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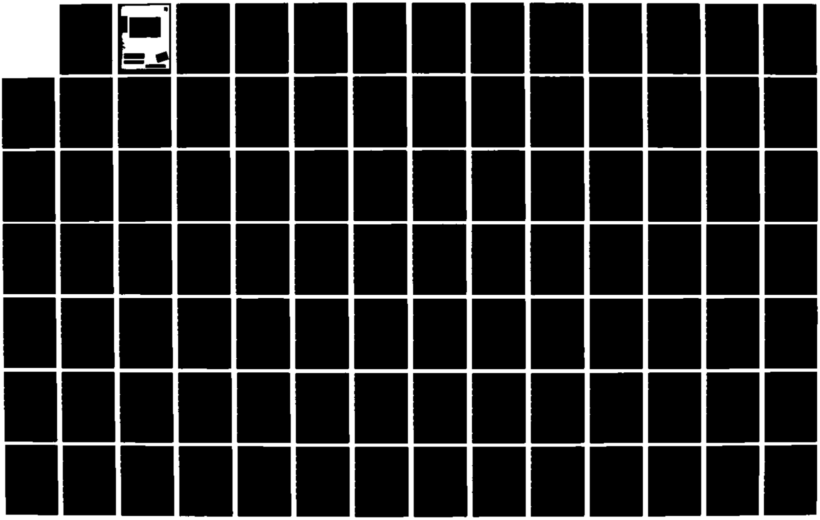

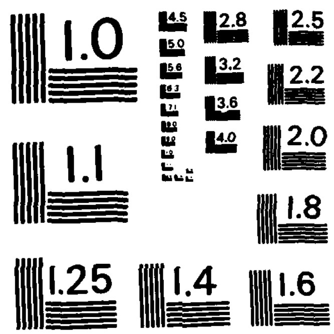
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DEPARTMENT OF OCEAN ENGINEERING

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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METHODOLOGY FOR COMPUTER-SUPPORTED COMPARATIVE NAVAL SHIP DESIGN

by

Udo Helmut Rowley

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METHODOLOGY FOR COMPUTER-SUPPORTED COMPARATIVE NAVAL SHIP DESIGN

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METHODOLOGY FOR COMPUTER-SUPPORTED

COMPARATIVE NAVAL SHIP DESIGN

by

UDO HELMUT ROWLEY

Submitted to the Department of Ocean Engineering on May 10, 1985 in partial fulfillment of the requirements for the degrees of Ocean Engineer and Master of Science in Mechanical Engineering.

ABSTRACT

Comparative Naval Ship Design is used to compare new designs for trend analysis or to determine new technology impact on the "whole" ship. This process is at present manually time-intensive and tailored to the individual study. This thesis proposes a standardized methodology to display and compare ship designs using present computer technology. With full preparation for it's implementation into a computer program, applicability is shown for direct interactive data base extraction, interfacing with the Navy's Advanced Surface Ship Evaluation Tool (ASSET) or simply using a microcomputer spreadsheet.

The proposed methodology will provide for a direct detailed graphical or tabular comparative analysis of any two ships, a bar graph analysis of up to six ships simultaneously, or a trend analysis to compare a new design to past similar designs. All proposed comparison parameters and indices are fully documented with definitions and significant relationships to overall ship impact. Additionally, a comparative analysis help option is presented to assist the designer in determining "impacts of" and "reasons for" significant differences of a two ship comparison.

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Thesis Reader: Professor Thomas P. Bligh
Title: Associate Professor of Mechanical Engineering

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CHAPTER 1

INTRODUCTION

1.1 Purpose

Naval architects and design engineers continuously show an interest in how a new design compares to previous ships of the same type or how a new technology impacts a design. The process of comparing designs is referred to as comparative naval ship design and the basic methods are documented in references (1) through (8) and (12) and (13). All these methods, however, are tailored to the particular presentation or comparison being performed and no "standardized" methodology exists. It is the intent of this thesis to provide this standard which can be applied to any naval ship in any stage of ship design. The thesis will further establish the methodology to allow these comparisons to be rapidly and interactively applied through the use of current computer technology. Although the theory will be similar for all ships, this thesis will concentrate only on naval combatants of the destroyer, frigate, and cruiser type.

1.2 Basic Methodology

Today's computers allow for the use of large, complex data bases and design synthesis models. These tools have the capability of generating and storing many different new design ships and new technology variants. While providing this extensive amount of information, it is presently time consuming and difficult to absorb and analyse it manually to find feasible, realistic designs. Since the computer can generate the information, it also provides the capability to compare it. This thesis will concentrate on how the computer can store and display the data to allow the user to make quantitative, judgements on the comparison of different designs to:

a. perform realistic technological assessments on existing ships, future ships or ship variants.

a. identify major differences and explain reasons why the differences occured for:

- baseline ships versus variants
- existing data bank ships versus new designs
- existing data bank ships versus foreign designs

b. determine the design requirements, technical design standards and overall design philosophy which governed the development of the designs.

The comparative naval ship design problem has in the past been treated primarily in a manual mode. The author will present new methodology to perform the analysis using three new tools: the design synthesis model, the integrated data base and the microcomputer spreadsheet. Primary emphasis will be placed on the most complex of the new methods, which will be the proposed methodology to interactively interface with a data base and/or a synthesis model. The methodology developed here will be general to allow for application to any synthesis model program or integrated data base. A chapter of the thesis, however, will provide specific tailoring for implementation with the Navy Advanced Surface Ship Evaluation Tool (ASSET) program.

1.3 Ship Design Synthesis Models

A ship design synthesis model is defined as an engineering procedure which converts a set of performance requirements into a physical description of a ship which can satisfy these requirements. It is in most cases an iterative procedure providing continuous comparisons of the new iteration to the last "best" design. This process can be extremely time consuming for today's large and complex models in use. It is the author's opinion that the developed methodology may be adapted to any ship synthesis model output either directly or through a storage data base. This will allow the designer to compare the synthesized designs in a more rapid and accurate manner.

The primary ship synthesis models in use today for naval combatant ship design are the Naval Sea Systems Command (NAVSEA) DD08 and the David Taylor Naval Ship Research and Development Center ASSET. The Advanced Surface Ship Evaluation Tool (ASSET) is an interactive computer based total ship technology evaluation tool which would benefit greatly by the addition of a comparative ship design capability. The program itself, as well as the interface requirements of the developed methodology will be further discussed in section 7.

For indices that result in percentages, such as V_{dh}/VOL or W_1/DSP.fl, the differences will be calculated as the absolute value of the primary parameter (i.e. V_{dh} or W_1) which is always the numerator. For indices that do not result in percentages, such as W_2/SHP or L_{bp}, the difference will be calculated for the complete indice. In the former case of the absolute value comparison, the designer can easily note or even calculate the relative indice difference of the comparison by viewing the "composite" screen.

The "singular" type display, as shown in figure 3.1, is graphed on the bar-graph as the absolute value of the primary parameter (numerator) in the indice being investigated. An annotated absolute scale is shown at the bottom of the screen. Each bar will additionally contain the name of the parameter, the actual absolute value and the indice percentage. At the extreme right of the variant bar, the absolute percentage difference is displayed. As noted before, all differences will be calculated as variant related to baseline and will be annotated as positive (+) or negative (-) change.

The "composite" type stacked bar-graph display of figure 3.2 groups together all indices that account for 100% of the parameter used as the denominator of the indice. This display compares directly the relative percentage of each of the parameters without relating it to the absolute value. In this case, the actual indice percentage is used. Annotation of the graph shall include the percentage plus the name of the indice, as shown.

the recommended format of a tabular screen is shown in figure 3.3. Using "control keys", the user will have the ability to either go directly to a new screen if he knows the screen number or he may request an option screen which will open a screen "window" with available paths. These options will be further explained with the flow chart in section 3.6.

The "singular" and "composite" displays were developed to provide the designer with the maximum amount of information pertaining to each parameter and indice. To perform an accurate and meaningful comparison, the designer must know both the absolute difference of a parameter as well as the relative differences when the parameter is related to the group it belongs to. As in the appendix C example of screen 2-5 displayed in figures 3.1 and 3.2, the deckhouse volume absolute difference is -29.1%, indicating that DDG51 has a smaller deckhouse than DD963. The relative difference of the indice, deckhouse volume to total volume fraction (V_{dh}/VOL), however, is 25% for DD963 versus 19% for DDG51, which is only a -6% difference. Additionally from the example screen it can be noted that the hull volume fractions also show a 6% change in the positive direction, as expected, but with only a 1.2% absolute change.

The convention that is therefore established is to calculate all differences or "delta's" in the same manner as:

[(Variant - Base)/(Base)] * 100

ex: [(184057 - 259738)/259738] * 100 = -29.1%

CHAPTER 3

TWO-SHIP COMPARATIVE ANALYSIS

3.1 Methodology

This is the most detailed comparison of all analysis options, allowing the user to compare any two ships available in the data bank. He must select one to be the baseline and the second to be a variant, where all comparisons will be variant to baseline. Ships will be compared in three major levels. The first will consist of comparing the primary characteristics of the two designs. The subsequent second tier of comparison is used to compare resource allocations and the third level will involve more detail in a functional investigation mode.

The three levels are each further subdivided into "screens". This method was used to allow the grouping of similar indices together while maintaining a usable screen size. All graphic screens will be in the form of bar charts comparing the indices in a "singular" comparison as in figure 3.1 or a "composite" comparison as displayed in figure 3.2. All graphic screens have been limited to no more than eight items for display. This number was selected to be the most that could effectively be displayed on the average terminal. Tabular screens may be multi-page and thus have no restriction on the number of items allowed. Multi-page screens should have a prompt to display the number of pages and allow the user to select the page number desired. An example of

Figure 2.1 shows the basic entry into the program or module. Letters and numbers in circles indicate continuations of either input or output from other flow charts discussed in the thesis.

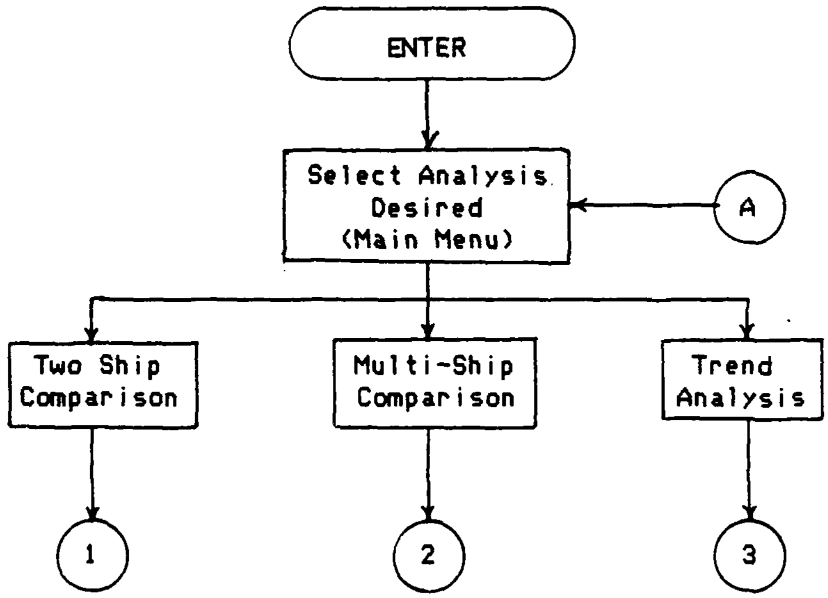

Figure 2.1 Program Entry Flow Chart

2.4 Types of Analysis

Three different types of analysis methods will be available to the user. The first and most complex involves a direct comparison between two ships, designated as a baseline and variant where all comparisons relate the variant to the baseline ship. A comparative analysis routine will be available in this mode to assist the designer in his search for differences.

The second method of analysis is a multi-ship comparison, whereby the user has the option, for a limited number of available indices, to compare up to six data bank ships on a "one indice at a time" basis.

The third type of comparison is a trend analysis which will allow the user to plot his selected design with established present and past fleet combatants, for a selected number of indices. This will allow him to analyse where his design fits into current trends.

Each of the above types of analysis will be discussed in detail in their respective chapters.

2.5 Programming Notes

Since it may be desired to program this methodology at a future date, this topic will be used where necessary to amplify information regarding the author's views on how the section should or could be programmed. Additionally, a flow chart to assist the programmer will be presented for each type of analysis.

further broken down into the rating structure of Officer, Chief Petty Officer (CPO) and Enlisted crew. A second breakdown is by departmental utilization of personnel, where in the case of combatant ships, the departments include:

- Navigation/Administration
- Combat Systems
- Operations
- Engineering
- Supply
- Aviation

2.3.6 Cost Accounting System

The Navy Standard Simplified P8 Cost Breakdown was selected as the easiest method of comparing actual dollar costs. The input P8 values were then manipulated to provide the most meaningful direct comparison. The P8 input cost values required are:

- Planning
- Basic Construction (including full breakdown by SWBS)
- Change Order
- Electronics
- H.M.&E.
- Other Cost
- Ordnance
- Escalation
- Project Manager Growth

2.3.3 Volume/Space Classification System

The current Ships Space Classification System (SSCS) was selected for all volume related indices. The utilization of all space is divided into five functional areas:

- Mission Support
- Human Support
- Ship Support
- Ship Mobility
- Unassigned

The sum of these five groups will encompass the total enclosed volume, including the superstructure.

The breakdown of these groups is available in reference (23).

2.3.4 Electrical Classification System

The current electrical classification system in use follows the Ships Work Breakdown Structure (SWBS) exactly, except that it does not include Group 100, since structures requires no electrical power. All other equipment's electrical requirements will be classified in the same three digit category as its corresponding weight.

2.3.5 Manning Classification System

There is no "standard" manning classification system, however, a useful breakdown was not difficult to obtain. Manning is classified by the number of accomodations, or berths, onboard and the actual total complement required to operate the ship. This is

- specific ratios
- capacity/size ratios

The definitions and significances of these types of design indices are discussed in appendix F.

2.3.2 Weight Classification System

The present standard Navy weight classification system, Ships Work Breakdown Structure (SWBS), was selected to categorize all weight indices. The system groups the various weight items into seven categories, which are formed according to functional area. The sum of these weight groups make up the lightship displacement. These seven groups are:

- 100 Structures
- 200 Propulsion
- 300 Electrical
- 400 Command and Surveillance
- 500 Auxiliary
- 600 Outfit and Furnishings
- 700 Armament

The full load displacement is then obtained by adding an eighth group (F00), referred to as the ships variable loads. This group includes crew and effects, potable water, ordnance, fuel, stores and aircraft.

A more detailed listing of the components in each weight group is available in reference (22).

a. The design indices and parameters must serve to provide meaningful indicators that provide quantitative comparisons for:

- performance requirements
- design standards
- design philosophy

b. Design indices and parameters must be:

- meaningful (provide indication of design practice and standards)
- simple to calculate
- simple to analyse

c. Design indices and parameters are based on a functional breakdown of the ship and include the use of a:

- standardized weight classification system (SWBS)
- standardized space/volume classification system (SSCS)
- standardized electrical classification system
- standardized manning classification system
- standardized cost accounting system

d. Standard ratios and fractions to be used included:

- weight fractions
- weight densities
- volume fractions
- energy fractions
- manning fractions

2.2 Detail of Analysis

The guiding principles to the level of detail required in the analysis were:

a. to allow sound naval architectural explanation of the differences which exist in the compared designs.

b. to allow assessment of whether a new design or a variant is "good" or "bad" and why.

c. to allow the designer to make sound judgements on how to best improve the design.

d. to analyse tradeoffs and the impact of changes made to a baseline design.

e. to analyse the impact of adding a new technology to an existing or new design.

2.3 Methods of Analysis

The selection of the proper indices and parameters for examination, as well as the types of analysis to be performed were critical to the proper flow of the methodology. The determination was made to perform analysis and comparison of the ship's primary characteristics, resource allocation and functional investigation. The primary method of comparison would be in the form of percentages, rather than real values.

2.3.1 Selection of Indices

The following criteria was used for selection of the parameters and indices:

CHAPTER 2

COMPARATIVE METHODOLOGY

2.1 Definition of Analysis

The framework of the comparative ship design analysis established in this thesis is based on the current methods of analysis used by C. Graham, J. Kehoe, et al in references (4), (5), (12), and (13). These analysis were limited to existing ships and were not easily applied to the case of a two ship comparison for technology assessment. This type of analysis required a further in-depth study of specific weight and volume changes. Based on these assessments, the approach was modified to meet the need.

Since the comparative process would be computer based, the determination was made to use computer graphics as much as possible to assist the user by graphical interpretation of data. When graphics were not possible, a direct tabular comparison would be used. Additionally, the use of the storage and calculation capability of the computer allowed for a larger assortment of data to be examined, which was previously limited due to the extensive time required for these type of cumbersome calculations, as well as the nonavailability of a centralized ship design data base.

The approach stressed not only the comparative analysis but also the use of the methodology as a design and technology assessment tool.

computer aided selection process and computer programming notes will be presented in each major section of the thesis, as required.

1.7 Approach

The thesis will first provide an overview of the types and details of analysis required in chapter 2. Chapters 3 through 5 will then concentrate on the details of the three primary methods selected to perform a comparative naval ship design analysis. The interface requirements to an integrated data base and to the ASSET program are described in chapters 6 and 7. Finally conclusions and recommendations are drawn in chapters 8 and 9. Appendix F concentrates largely on the definitions and significances of the indices that were selected and appendices C and D are sample investigations performed to verify the methodology and program flow.

comparative analysis requiring only that the parameters be input for each ship or variant. In fact, this type of a spreadsheet serves to function as both a data base and computational model. Appendices C and D used this type of comparison to provide an example of how the methodology is used.

1.6 Interactive Computer Technology

The best method of presenting the methodology introduced in this thesis is through the use of a computer program written specifically for this application, using the latest in interactive computer graphics technology.

Computer graphics is defined as the use of a computer to define, store, manipulate, and present pictorial output. Interactive technology allows the user to influence the program to allow him to see the picture he desires. Although, the basic graphics used in the methodology is in the form of bar charts and graphs, the interactive ability to shift between different presentations is the key to the successful and rapid utilization of the program for comparative analysis. This could be performed with current technology by the use of "graphic windows" or "screen partitioning" which open on the screen and allow a new menu selection. These methods are now common to even many of the smaller microcomputers and readily available on the larger mainframe graphics packages. Specifics regarding the type of

1.4 Data Bases

A data base in the context of this thesis is defined as an electronic filing system where information is stored in a pre-determined structure or hierarchy. In a naval ship design environment, the data base must be a consistent and unambiguous source of information about the ship's configuration and equipment.

At present, the Navy design community does not have a central data base storage facility for past designs or future conceptual designs. There is, however, a large effort underway to achieve this capability, which should be available within the next two years. Since a data base has the ability to store almost unlimited information about a design, it is with this premise and for this primary use that the methodology was developed. A further discussion regarding the comparative methodology interface to a data base is discussed in section 6.

1.5 Spreadsheet Analysis

The simplest method of applying this methodology is through the use of a "spreadsheet" type of software program available for almost all microcomputers. This requires that the basic input information be available in the first part of the spreadsheet thus allowing for a simple input with the actual mathematics being performed by the computer. Although the initial setup and programming of the spreadsheet is time consuming, the basic format can be copied, saved, and then used again and again for different

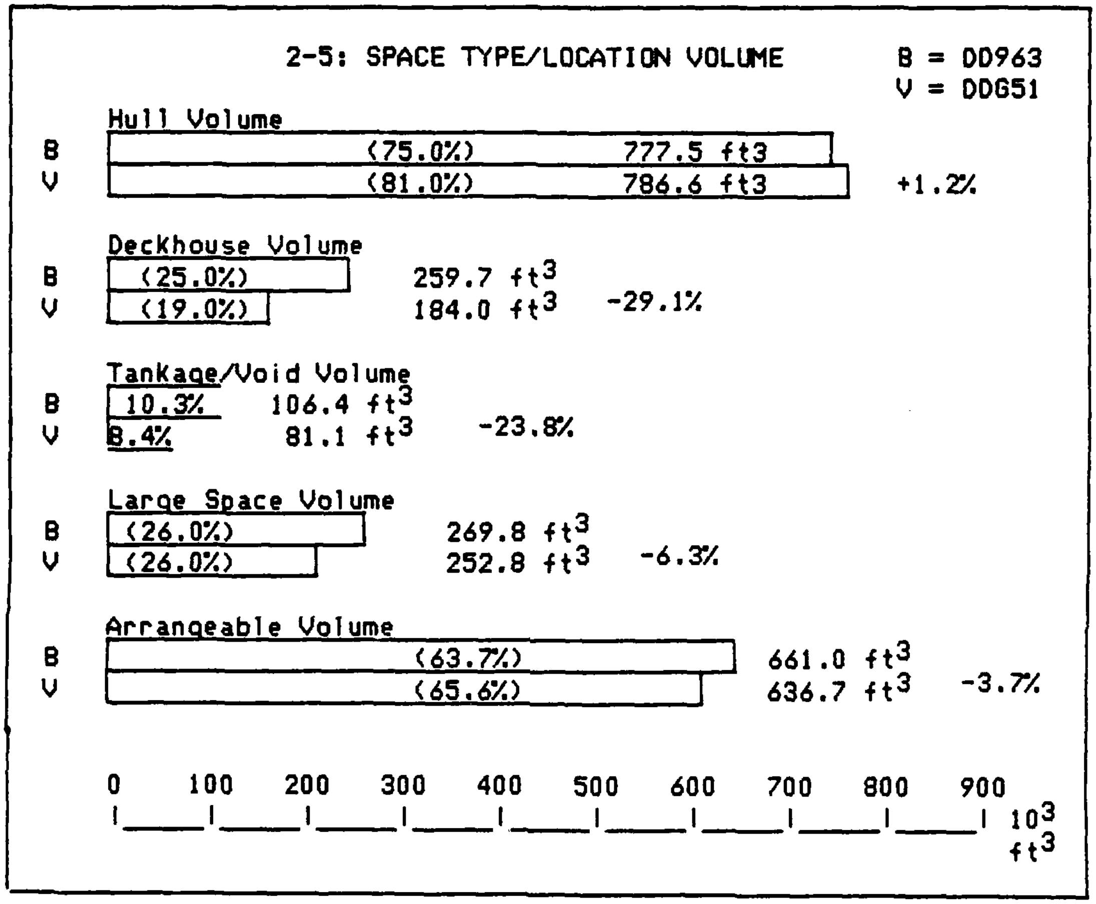

Figure 3.1 "Singular" Display Graphic Screen Example

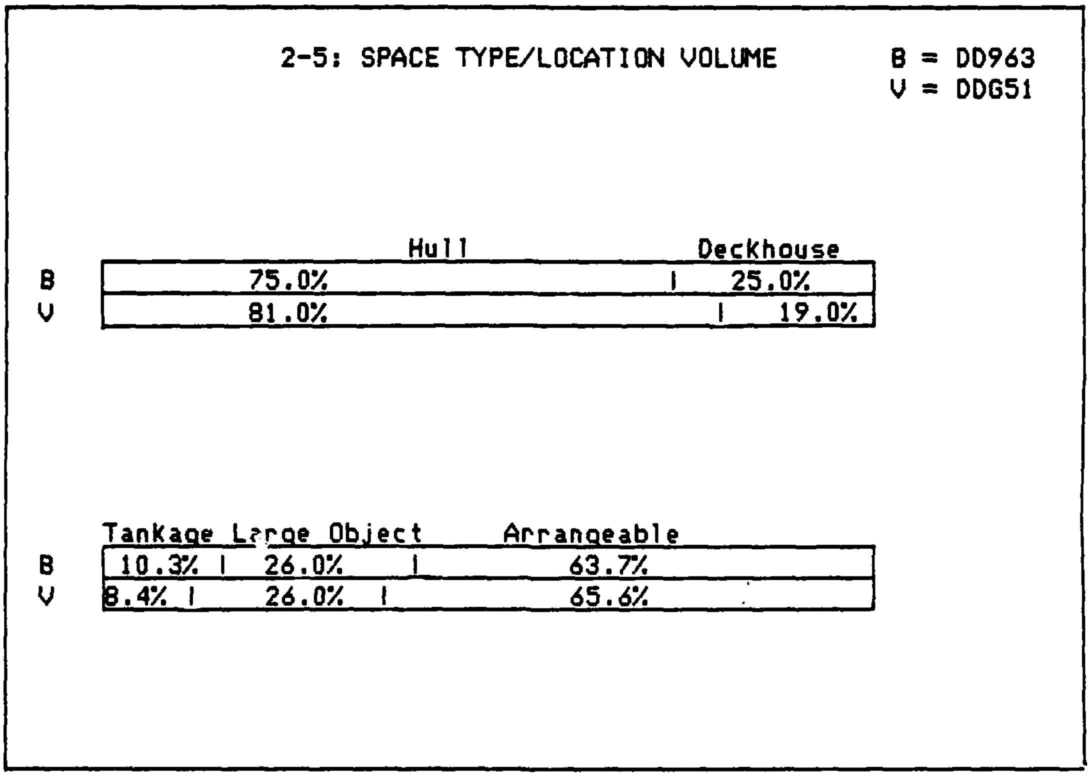

Figure 3.2 "Composite" Display Graphic Screen Example

1-2: SHAPE CHARACTERISTICS B = DD963
V = DDG51

	B	V	DELTA
Displacement/Length rat.	52.9	83.5	57.8%
Prismatic Coeff	.570	.604	6.0%
Max Section Coeff	.823	.825	.2%
Waterplane Coeff	.724	.780	7.7%
Length/Beam ratio	9.62	7.90	-17.9%
Length/Draft ratio	29.39	23.30	-20.7%
Beam/Draft ratio	3.06	2.95	-3.5%
Draft/Depth ratio	.43	.48	11.6%
Length/Depth ratio	12.60	11.15	-11.5%

PAGE 1 OF 1

Figure 3.3 Tabular Display Screen Example

The tabular screen of figure 3.3 is displayed similar to the spreadsheet analysis performed in appendices C and D where the "Delta" value is calculated as previously explained. All other aspects of the tabular display are self-explanatory.

Upon entering this level of analysis, the user will be prompted by menu for the screen he desires to examine. If the screen has both a "singular" and "composite" display available, the user will be prompted to make a choice. While the screen is displayed, the user may exercise a "control key" for further options, where one of the options will be to change from "singular" to "composite" or vice versa. The exact program flow will be explained in greater detail in section 3.6.

During the comparisons, the user will have the option to highlight major differences in reverse video. If this option is exercised then the user selects a "Delta" percentage that he considers to be a "major difference". He may change his selection by increasing or decreasing the percentage at any time during his analysis. To assist him in discovering the "reason for" or "impact of" a significant change, he may select the "computer-assisted comparative analysis" option explained in section 3.5.

The three levels of analysis and the types of indices or parameters investigated in each level are:

LEVEL 1: Primary Characteristics

- Size

- Shape
- Ship Performance
- HM&E System Selection
- Combat Systems Selection

LEVEL 2: Resource Allocation

- Weight
- Volume
- Energy
- Manning
- Cost

LEVEL 3: Functional Investigation

- Combat System
- Containment
- Main Propulsion
- Electrical & Auxiliary
- Human Support
- Margin Summary
- Survivability (*)

* recommended for future implementation as survivability parameters and requirements are further defined.

The subsequent sections provide a brief overview of each level and the indices used on each screen. Each title of the screen indicates in parenthesis whether the recommended format is graphical or tabular. It the screen is graphical, an indication will be present whether the screen should have a "singular", [s], display or a "composite", [c], display or both, [s,c]. Each indice and parameter is explained in detail in appendix F. Additionally, a summary of all screens by title and subtitle may be found in appendix A.

3.2 Level 1: Primary Characteristics

The initial step of viewing the primary characteristics of the design and comparing them to a baseline or data bank ship involves the availability of five screens. These describe and compare the size, shape, ship performance, HM&E selection and combat system selection. All comparisons for these screens will be tabular.

Each screen is listed below with its associated indices, symbol, and units, where applicable.

Screen 1-1: Cost and Size Characteristics (tabular)

TOTAL COSTS:

NOTE: Choice of selection of "lead ship" or "follow ship" costs

- Basic Construction Cost	C_{bc}	$
- Combat System GFE Costs	C_{csgfe}	$
- Other Costs (see Appendix F for breakdown)	C_{oth}	$
- Total Ship Cost ($C_t=C_{bc}+C_{csgfe}+C_{oth}$)	C_t	$

SHIP SIZE:

- Full Load Displacement	Δ_{fl}	tons

- Light Ship Displacement	Δ_{ls}	tons
- Total Enclosed Volume	∇	ft^3
- Ship Density Full Load	Δ_{fl}/∇	lbs/ft^3
- Ship Density Light Ship	Δ_{ls}/∇	lbs/ft^3
- Length between perpendiculars	L_{bp}	ft
- Length overall	L_{oa}	ft
- Beam at waterline	B_{wl}	ft
- Beam (max at deck edge)	B_{max}	ft
- Depth at midships	D	ft
- Draft (maximum)	T	ft

Screen 1-2: Shape Characteristics (tabular)

- Displacement/Length ratio	$\Delta_{fl}/(.01L_{bp})^3$	tons/ft
- Prismatic Coefficient	C_p	
- Maximum Section Coefficient	C_x	
- Waterplane Coefficient	C_w	
- Length/Beam ratio	L_{bp}/B_{wl}	
- Length/Draft ratio	L_{bp}/T	
- Beam/Draft ratio	B_{wl}/T	
- Draft/Depth ratio	T/D	
- Length/Depth ratio	L_{bp}/D	

Screen 1-3: Ship Performance (tabular)

- Mobility:

* Max Sustained Speed (80% power)	kts
* Max Trial Speed (100% power)	kts

* Range at Endurance Speed		NM @Kts
* Endurance Period due to:		
Fuel at endurance speed		days
Stores		days
Chilled Stores		days
Frozen Stores		days
* Shaft Horsepower Available		SHP
* Shaft Horsepower Reqd at endurance speed		SHP
* Shaft Horsepower Reqd at sustained speed		SHP
- Hull Efficiency		
* Drag (sustained speed)	R_{Ts}	lbf
* Drag (endurance speed)	R_{Te}	lbf
* Bales Rank		
- Survivability:		
* Blast		psi
* Fragmentation		level
* Shock		ksf
* NBC		
* Noise Signature		
* IR Signature		
* Radar Signature		

Screen 1-4: HM&E System Selection (tabular)

Length of information will require a menu driven multi-page screen.

- Main Propulsion:
  * Total Boost Pwr Avail/Reqd at Sust. Spd/Growth Potential
  * Boost Engine Type/Number/Rating
  * Cruise Engine Type/Number/Rating
  * Transmission System Type
  * Propeller Type/Number/RPM
  * Propeller Open Water Efficiency (sustained spd)
  * Propeller Open Water Efficiency (endurance spd)
  * Propulsion Coefficient (PC)
  * Specific Fuel Consumption Rate (SFC) @ Endurance Spd
  * Specific Fuel Consumption Rate (SFC) @ Sustained Spd
  * Other (Comment Array)
- Electric Power:
  * Total 60 Hz KW Available/Maximum Load/Growth Potential
  * Total 400 Hz KW Available/Maximum Load/Growth Potential
  * 60 Hz Generator Type/Number/Rating
  * 400 Hz Generator Type/Number/Rating
  * Specific Fuel Consumption Rate (SFCA)
  * Other (Comment Array)
- Auxiliary
  * Total AC Available/Maximum Load/Growth Potential
  * AC Type/Number/Rating
  * Heating Type/Rating
  * Firepump Type/Number/Rating
  * Seawater Pump Type/Number/Rating

* HP Air Compressor Type/Number/Rating
* LP Air Compressor Type/Number/Rating
* Distilling Plant Type/Number/Rating
* Boats Type/Number
* Steering units Type/Number
* Anchors Type/Number/Length of Chain
* UNREP Capability
* Other (Comment Array)

- Structure/Materials
  * Hull Materials (array)
  * Deckhouse Materials (array)
  * Hull Frame Type/Spacing
  * Deckhouse Frame Type/Spacing
  * Other (Comment Array)
- Deck Heights
  * Number of Internal Decks in Hull
  * Number of Internal Decks in Deckhouse
  * Internal Deck Heights (array)
  * Hull Average Deck Height
  * Other (Comment Array)
- Manning
  * Total Accomodations/Total Complement/Growth Potential
  * Total Complement (OFF/CPO/ENL)
  * Habitability Classification
  * Flag configured

* Other (Comment Array)

Screen 1-5: Combat Systems Selection (tabular)

Combat systems are compared by warfare areas. This may require some systems to be displayed in more than one area or category. Length of information will require a multi-page menu driven screen.

- Anti-Air Warfare (AAW)
    * Armament
    * Sensors
    * Aviation Capabilities
- Anti-Submarine Warfare (ASW)
    * Armament
    * Sensors
    * Aviation Capabilities
- Surface/Strike Warfare (SUW)
    * Armament
    * Sensors
    * Aviation Capabilities
- Command, Control, Communications & Intelligence (C_{3I})
    * Communications
    * Electronic Warfare
    * Control

3.3 Level 2: Resource Allocation

This level consists of thirteen screens which depict the allocation of ship physical resources. These resources include weight, volume, energy, manning and cost, and are classified by using existing consistent conventions.

Each of the screens is listed as being either graphical or tabular and indicates whether the display should be "singular", "composite", or both. Where a "composite" screen is indicated, the parameters that should equal 100% are annotated. In some cases, only one "composite" bar-graph will exist in this mode of display.

Screen 2-1: SWBS Weight Fractions (graphical [s,c])

Uses the standard Navy Ship Work Breakdown Structure (SWBS)[22].

Option will exist to select either full load or light ship displacement as the denominator of the fraction. The sum of the weight groups will only equal 100% for the light ship case since load weight is not included in this screen.

General symbol: Δ => select either Δ_{ls} or Δ_{fl}

- Structural	W_1/Δ
- Main Propulsion	W_2/Δ
- Electrical	W_3/Δ
- Command and Surveillance	W_4/Δ
- Auxiliary Systems	W_5/Δ
- Outfit & Furnishing	W_6/Δ

- Armament W_7/Δ
- Margin W_m/Δ

$= 100\%$

Screen 2-2: Load Weight Fractions (graphical [s,c])

Parameters are based on load weights as specified in the Navy standard Ships Work Breakdown Structure (SWBS)[22].

- Liquid (fuel & lubricants) (F4) W_{fuel}/W_{ld}
- Crew and Effects (F1) W_{ce}/W_{ld}
- Ordnance (F2-F23-F26) W_{ord}/W_{ld}
- Aviation (F23+F26) W_{av}/W_{ld}
- Others (F3+F5+F6) W_{oth}/W_{ld}

$= 100\%\ W_{ld}$

- Total Load Weight to Full Load Ratio W_{ld}/Δ_{fl}
  $(W_{ld} = W_{fuel}+W_{ce}+W_{ord}+W_{av}+W_{oth})$
- Light Ship Weight to Full Load Ratio Δ_{ls}/Δ_{fl}

$= 100\%\ _{fl}$

Screen 2-3: Functional Weight Allocation Fractions (graphical [s,c])

For this screen, weight margin is proportionally distributed throughout the weight groups SWBS W_1 to W_7.

W_{mx} = portion of margin allocation to SWBS group 'x'

$W_{mx} = (\%W_x/(\text{sum } \%W_1 \ldots W_7)) * W_m$

$\%W_x$ = percentage of SWBS group 'x' (screen 2-1)

- Light Ship Combat System Weight W_{csl}/Δ_{ls}
  ($W_{csl} = W_4+W_7+W_{m4}+W_{m7}$)
- Light Ship Machinery Weight W_{mal}/Δ_{ls}
  ($W_{mal} = W_2+W_3+W_5+W_{m2}+W_{m3}+W_{m5}$)
- Light Ship Containment Weight W_{cl}/Δ_{ls}
  ($W_{cl} = W_1+W_6+W_{m1}+W_{m6}$)

  $= 100\% \Delta_{ls}$

- Full Load Combat System Weight W_{csf}/Δ_{fl}
  ($W_{csf} = W_4+W_7+W_{ord}+W_{av}+W_{m4}+W_{m7}$)
- Full Load Machinery Weight W_{maf}/Δ_{fl}
  ($W_{maf} = W_2+W_3+W_5+W_{fuel}W_{m2}+W_{m3}+W_{m5}$)
- Full Load Containment Weight W_{cf}/Δ_{fl}
  ($W_{cf} = W_1+W_6+W_{ce}+W_{oth}+W_{m1}+W_{m6}$)

  $= 100\% \Delta_{fl}$

Screen 2-4: SSCS Volume Fractions (graphical [s,c])

Uses standard Navy Ships Space Classification System (SSCS)[23].

- Mission Support V_1/∇
- Human Support V_2/∇
- Ship Support V_3/∇
- Ship Mobility V_4/∇
- Unassigned V_5/∇

  $= 100\% \nabla$

Screen 2-5: Space Type/Location Volume Fraction (graphical [s,c])

- Hull Volume V_{hull}/∇
- Deckhouse Volume V_{dh}/∇

  $= 100\% \nabla$

W_{ce} = crew and effects load weight (F1)

W_{6cr}= crew related group 6 outfit and furnishings
($W_{6cr}= W_{64+65+66+67}$)

W_{pw} = potable water weight (F52)

- Crew and Effects Weight	W_{ce}/W_{HS}
- Outfit and Furnishings Weight	W_{6cr}/W_{HS}
- Potable Water Weight	W_{pw}/W_{HS}
	= 100% W_{HS}

VOLUME:

- Living Volume	$V_{2.1}/V_2$
- Food Service/Messroom/Lounge Volume	$V_{2.2}/V_2$
- Medical/General Services/Other Vol	$V_{2.3\ thru\ 2.7}/V_2$
	= 100% V_2

Screen 3-12: Human Support Indices (tabular)

HUMAN SUPPORT DRIVERS:

- Human Support Weight Fraction	W_{HS}/Δ_{f1}	
- Human Support Specific Weight	W_{HS}/M_a	tons/man
- Total Accomodations Ship Size Ratio	M_a/Δ_{f1}	men/1Kton

RELATED HUMAN SUPPORT RATIOS:

- Human Support Density	W_{HS}/V_2	lbs/ft^3
- Personnel Living Space Specific Vol ($V_{2.1}$ = Living Space)	$V_{2.1}/M_a$	ft^3/man
- Human Support Specific Volume	V_2/M_a	ft^3/man
- Human Support Specific Area	A_2/M_a	ft^2/man
- Officer Living Area per man	$A_{2.11+2.211}/M_{aoff}$	ft^2/man

- Missiles & Rockets Vol	$V_{1.22+1.23}/V_{1.2}$	
- Other Armament Vol	$V_{1.24+1.25+1.26+1.27}/V_{1.2}$	
	$= 100\%\ V_{1.2}$	

Screen 3-10: Combat Systems Indices (tabular)

COMBAT SYSTEMS DRIVERS:

- Armament Weight Fraction	W_7/Δ_{f1}	
- Armament Capacity Size Ratio ($\#_1$ = number of launchers)	$\#_1/\Delta_{f1}$	lchr/1Ktons
- Armament Specific Weight	$W_7/\#_1$	1Ktons/lchr
- C&S Weight Fraction	W_4/Δ_{f1}	
- C&S Capacity Size Ratio ($\#_s$ = number of sensors)	$\#_s/\Delta_{f1}$	snsr/1Ktons
- C&S Specific Weight	$W_4/\#_s$	1Ktons/lchr

RELATED COMBAT SYSTEM RATIOS:

- Combat System Density	W_{csf}/V_1	lbs/ft^3
- Command and Surveillance Density	$W_4/V_{1.1}$	lbs/ft^3
- Armament Density	$W_7/V_{1.2}$	lbs/ft^3
- Combat System KW/Weight Ratio	E_{cs}/W_{csf}	KW/ton
- Combat System Cost/Weight Ratio	C_{cs}/W_{csf}	$/ton

Screen 3-11: Human Support Breakdown (graphical [s,c])

M_a = total accomodations

M_{axxx} = accomodations for 'xxx' personnel

WEIGHT:

$$W_{HS}=W_{ce}+W_{6cr}+W_{pw}$$

W_{HS} = total human support weight

COMMAND AND SURVEILLANCE WEIGHT:

- Interior/Exterior Communications Wt	W_{43+44}/W_4
- Surface Surveillance Wt	W_{45}/W_4
- Underwater Surveillance Wt	W_{46}/W_4
- Other C&S Wt	$W_{41+42+47+48+49}/W_4$
	$= 100\%\ W_4$

ARMAMENT WEIGHT:

- Guns and Ammo Wt	W_{71}/W_7
- Missiles and Rockets Wt	W_{72}/W_7
- Other Armament Wt	$W_{73\text{ thru }79}/W_7$
	$= 100\%\ W_7$

COMBAT SYSTEMS VOLUME:

- Command and Surveillance Volume	$V_{1.1}/V_1$
- Armament Volume	$V_{1.2}/V_1$
- Aviation Volume	$V_{1.3}/V_1$
	$= 100\%\ V_1$

COMMAND AND SURVEILLANCE VOLUME:

- Interior/Exterior Communications Vol	$V_{1.11+1.15}/V_{1.1}$
- Surface Surveillance Vol	$V_{1.121}/V_{1.1}$
- Underwater Surveillance Vol	$V_{1.122}/V_{1.1}$
- Other C&S Vol	$V_{1.13+1.14+1.16}/V_{1.1}$
	$= 100\%\ V_{1.1}$

ARMAMENT VOLUME:

- Guns and Ammo Vol	$V_{1.21}/V_{1.2}$

VOLUME:

NOTE: $(V_{ax} = V_{3.5+4.3-4.33})$
$V_{3.5}$ = Deck systems
$V_{4.3}$ = Auxiliary Machinery
$V_{4.33}$= Auxiliary Space Electric

- Deck Systems Volume	$V_{3.5}/V_{ax}$	
- Auxiliary Machinery Volume	$(V_{4.3}-V_{4.33})/V_{ax}$	
	$= 100\%\ V_{ax}$	

Screen 3-8: Auxiliary Indices (tabular)

AUXILIARY DRIVERS:

- Auxiliary Weight Fraction	W_5/Δ_{fl}	
- Auxiliary Specific Weight	W_5/∇	lbs/ft^3
- Ship Specific Volume	∇/Δ_{fl}	ft^3/ton

RELATED AUXILIARY RATIOS:

- Auxiliary Density	W_5/V_{ax}	lbs/ft^3
- Auxiliary Volume Fraction	V_{ax}/∇	
- Auxiliary KW/Weight Ratio	E_5/W_5	KW/ton
- Auxiliary Cost/Weight Ratio	C_5/W_5	\$/ton

Screen 3-9: Combat Systems Breakdown (tabular)

NOTE: may require multipage screen

COMBAT SYSTEMS WEIGHT:

- Command and Surveillance Wt	W_4/W_{csf}
- Armament Wt	W_7/W_{csf}
- Aviation Wt	W_{av}/W_{csf}
- Ordnance Wt	W_{ord}/W_{csf}
	$= 100\%\ W_{csf}$

- Machinery Box Electric Volume	$V_{4.15}/V_e$	
- Auxiliary Space Electric Volume	$V_{4.33}/V_e$	
	$= 100\%\ V_e$	

Screen 3-6: Electrical Indices (tabular)

ELECTRICAL DRIVERS:

- Electrical Weight Fraction	W_3/Δ_{fl}	
- Electrical Specific Weight	W_3/E_i	lbs/KW
- Electrical Capacity Ship Size Ratio	E_i/Δ_{fl}	KW/ton

RELATED ELECTRICAL RATIOS:

- Electrical Density	W_3/V_e	lbs/ft^3
- Electrical Volume Fraction	V_e/∇	
- Power Generation Specific Weight	W_{31}/E_i	lbs/KW
- Electrical Specific Volume	V_e/E_i	ft^3/KW
- Electrical System KW/Weight Ratio	E_3/W_3	KW/ton
- Electrical System Cost/Weight Ratio	C_3/W_3	$/ton

Screen 3-7: Auxiliary Breakdown (graphical [s,c])

WEIGHT:

- Climate Control Wt	W_{51}/W_5
- Sea Water/Freshwater Systems Wt	W_{52+53}/W_5
- Fluid Systems Wt	$W_{54+55+59}/W_5$
- Ship Control Wt	W_{56}/W_5
- Replenishment/Mechanical Handling Wt	W_{57+58}/W_5
	$= 100\%\ W_5$

- Main Prop Ship Size Ratio	SHP/Δ_{fl}	SHP/ton
- Drag to Displacement Ratio (endurance)	R_{Te}/Δ_{fl}	lbf/ton
- Drag to Displacement Ratio (sustained)	R_{Ts}/Δ_{fl}	lbf/ton
- Propulsion Coefficient	PC	

RELATED MAIN PROPULSION RATIOS:

- Main Propulsion Density	W_2/V_{pt}	lbs/ft^3
- Main Propulsion Volume Fraction	V_{pt}/∇	
- Propulsion Units Specific Weight	W_{23}/SHP	lbs/SHP
- Transmission/Propeller Specific Weight	W_{24}/SHP	lbs/SHP
- Support/Fluids Specific Weight	$W_{25+26+29}/SHP$	lbs/SHP
- Propulsion & Trans Specific Volume	V_{pt}/SHP	ft^3/SHP
- Propulsion Systems Specific Volume	$V_{4.1-4.15}/SHP$	ft^3/SHP
- Trans/Propeller Specific Volume	$V_{4.2}/SHP$	ft^3/SHP
- Propulsion KW/Weight Ratio	E_2/W_2	KW/ton
- Propulsion Cost/Weight Ratio	C_2/W_2	\$/ton

Screen 3-5: Electrical Plant Breakdown (graphical [s,c])

WEIGHT:

- Power Generation Wt	W_{31}/W_3
- Power Distribution Wt	W_{32}/W_3
- Lighting Wt	W_{33}/W_3
- Support System Wt	W_{34+39}/W_3
	$= 100\%\ W_3$

VOLUME:

NOTE: $(V_e = V_{4.15+4.33})$
$V_{4.15}$= Machinery Box Electric
$V_{4.33}$= Auxiliary Space Electric

RELATED CONTAINMENT RATIOS:

- Containment Density	W_{cf}/V_c	lbs/ft^3
- Basic Hull Structure Density	$W_{11+12+13+14}/\nabla_{hull}$	lbs/ft^3
- Deckhouse Structure Density	W_{15}/∇_{dh}	lbs/ft^3
- Foundations Weight Fraction	$W_{18}/(W_{2+3+4+5+7})$	
- Containment Cost/Weight Ratio	C_c/W_{cf}	\$/ton

Screen 3-3: Main Propulsion Breakdown (graphical [s,c])

WEIGHT:

- Propulsion Units Wt	W_{23}/W_2
- Transmission and Propulsor Wt	W_{24}/W_2
- Propulsion Support System Wt	$W_{25+26+29}/W_2$
- Other Propulsion Wt	W_{21+22}/W_2
	= 100% W_2

VOLUME:

NOTE: $(V_{pt} = V_{4.1+4.2-4.15})$
$V_{4.1}$ = Propulsion Systems
$V_{4.2}$ = Transmission and Propulsor
$V_{4.15}$ = Machinery Box Electric

- Propulsion Systems Volume	$V_{4.1-4.15}/V_{pt}$
- Transmission and Propulsor Volume	$V_{4.2}/V_{pt}$
	= 100% V_{pt}

Screen 3-4: Main Propulsion Indices (tabular)

MAIN PROPULSION DRIVERS:

- Main Propulsion Weight Fraction	W_2/Δ_{fl}	
- Main Propulsion Specific Weight	W_2/SHP	lbs/SHP

Each of the functions uses two screens, the first examines detailed weight and volume allocations while the second uses indices to aid in determining what drives the particular changes associated with that function.

Screen 3-1: Containment Weight Breakdown (graphical [s,c])

STRUCTURE WEIGHT:

- Shell and Supports	W_{11}/W_1
- Hull Structural Bulkheads and Decks	$W_{12+13+14}/W_1$
- Deckhouse	W_{15}/W_1
- Foundations	W_{18}/W_1
- Other Structural	$W_{16+17+19}/W_1$
	$= 100\%\ W_1$

OUTFIT AND FURNISHINGS WEIGHT:

- Crew Related	$W_{64+65+66+67}/W_6$
- Non-Crew Related	$W_{61+62+63+69}/W_6$
	$= 100\%\ W_6$

Screen 3-2: Containment Indices (tabular)

CONTAINMENT DRIVERS:

- Structural Weight Fraction	W_1/Δ_{f1}	
- Outfit and Furnishings Weight Fraction	W_6/Δ_{f1}	
- Total Hull Structure Specific Weight	W_1/∇	lbs/ft^3
- Outfit and Furnishings Specific Weight	W_6/∇	lbs/ft^3
- Ship Specific Volume	∇/Δ_{f1}	ft^3/ton

C_{xd} = distributed costs

$C_{xd} = [C_x/(\text{sum } \%C_1 \text{ thru } \%C_7)] * (C_{m+de+con+pr+oth-pmg})$

C_x = % cost of SWBS group 'x' (screen 2-11)

- Combat Systems Costs ($C_{cs} = C_{4+7+csgfe+pmg+4d+7d}$)	C_{cs}/C_t
- Machinery Costs ($C_{ma} = C_{2+3+5+2d+3d+5d}$)	C_{ma}/C_t
- Containment Costs ($C_c = C_{1+6+1d+6d}$)	C_c/C_t
	= 100% C_t

Screen 2-13: Cost fractions (tabular)

C_{ls} = Lead Ship Total Cost

C_{fs} = Follow Ship Total Cost

- Combat System GFE/Lead Ship Cost	C_{csgfe}/C_{ls}	
- Combat System GFE/Follow Ship Cost	C_{csgfe}/C_{fs}	
- Basic Construction/Lead Ship Cost	C_{bc}/C_{ls}	
- Basic Construction/Follow Ship Cost	C_{bc}/C_{fs}	
- Total Follow Ship Cost/Weight ratio	C_{fs}/Δ_{fl}	\$/ton
- Total Follow Ship Cost/Volume ratio	C_{fs}/∇	\$/ft^3

3.4 Level 3: Functional Investigation

This level further breaks down levels 1 and 2 into functional areas to allow further investigation into why the differences occurred and what the impact is on the overall design. The areas which are further investigated are combat systems, main propulsion, containment, electrical, auxiliary, human support, margins and survivability (for later implementation).

Choice of selection of "lead ship" or "follow ship" costs.

$$C_{bc}=C_1+\ldots+C_7+C_m+C_{de}+C_{con}+C_{pr}$$

$$C_{BC}=C_1+\ldots+C_7+C_m+C_{de}+C_{con}+C_{pr}+C_{HM\&E}$$

- Hull Structure	C_1/C_{bc}
- Propulsion Plant	C_2/C_{bc}
- Electric Plant	C_3/C_{bc}
- Command and Surveillance	C_4/C_{bc}
- Auxiliary Systems	C_5/C_{bc}
- Outfit and Furnishing	C_6/C_{bc}
- Armament	C_7/C_{bc}
- D & C Margin	C_m/C_{bc}
- Design and Engineering (Group 8)	C_{de}/C_{bc}
- Construction Services/Assembly (Group 9)	C_{con}/C_{bc}
- Profit	C_{pr}/C_{bc}
	= 100% C_{bc}
- HM&E GFE	$C_{HM\&E}/C_{BC}$

Screen 2-12: Functional Cost Allocation Fractions (graphical [s,c])

Choice of selection of "lead ship" or "follow ship" cost fraction

All non-SWBS related basic construction costs are distributed proportionally in the proportion allocated in screen 2-11.

All "Other Costs" are distributed proportionally as allocated in Screen 2-11 with the exception of P.M. Growth which is added directly to Combat Systems Costs.

- Machinery Electrical $(E_{ma}=E_2+E_3+E_5+E^*_{m3}+E^*_{m5})$ — E_{ma}/E
- Containment Electrical $(E_c=E_6+E^*_{m6})$ — $E_c\ /E$

E^* = for E_i selection only — = 100% E

Screen 2-9: Manning Allocation Fraction (graphical [s,c])

General symbol: M_a = total accomodations (OFF+CPO+ENL)

M_{xxx} = manning for 'xxx' personnel

- Officer ratio	M_{off}/M_a
- CPO ratio	M_{cpo}/M_a
- Enlisted ratio	M_{enl}/M_a
- Margin $(M_m = M_a - M_{off+cpo+enl})$	$M_m\ /\ M_a$
	= 100% M_a

SCREEN 2-10: Functional Manning Allocation Fractions (graphical [s,c])

NOTE: Manning margins are proportionally distributed

- Combat Systems manning ratio	M_{cs}/M_a
- Operations manning ratio	M_{ops}/M_a
- Engineering manning ratio	M_{eng}/M_a
- Nav/Admin manning ratio	M_{na}/M_a
- Supply manning ratio	M_{sup}/M_a
- Aviation manning ratio	M_{av}/M_a
	= 100% M_a

Screen 2-11: Basic Construction Cost Allocation (tabular)

NOTE: Uses standard Navy P8 Cost Breakdown structure.

FUEL USAGE:

Propulsion fuel usage is based on endurance speed. Electrical fuel usage is based on average 24 hour load.

NOTE: $SFCA_e$ = Generator SFC at 24 hr average load

SFC_e = Propulsion SFC at endurance speed

HP_{gene} = Generator Horsepower at 24 hr avg load

HP_{shpe} = Propulsion horsepower at endurance spd

FF_{gen} = Generator Fuel flow (lbm/hr)
($FF_{gen} = SFCA_e * HP_{gene}$)

FF_{mp} = Main Propulsion fuel flow (lbm/hr)
($FF_{mp} = SFC_e * HP_{shpe}$)

FF_t = Total fuel flow (lbm/hr)
($FF_t = FF_{gen} + FF_{mp}$)

- Propulsion Fuel Allocation	FF_{mp}/FF_t
- Electrical Fuel Allocation	FF_{gen}/FF_t
	= 100% FF_t

ELECTRICAL:

NOTE: (1) same selections as Screen 2-7 above

(2) Electric margin is proportionally distributed to E_3 through E_7 for E_i selection only. E_2 does not have a service life margin.

E_{mx} = portion of margin allocation to SWBS group 'x'

$E_{mx} = (\%E_x/(\text{sum } \%E_3 \ldots E_7)) * E_m$

$\%E_x$ = percentage of SWBS group 'x' (screen 2-7)

- Combat System Electrical ($E_{cs}=E_4+E_7+E^*_{m4}+E^*_{m7}$)	E_{cs}/E

Select:
10° day
90° day

Select:
Battle Condition
Cruise Condition

E = symbol to select either max or installed capacity
E_m only applicable when E_i selected

- Propulsion Plant	E_2/E
- Electric Plant	E_3/E
- Command & Surveillance	E_4/E
- Auxiliary	E_5/E
- Outfit and Furnishings	E_6/E
- Armament	E_7/E
- Margin (Aquisition + Service Life)	E_m/E
	= 100% E

Screen 2-8: Functional Energy Allocation Fractions
(graphical [s,c])

INSTALLED HP:

NOTE: HP_{shpi} = Total shaft horsepower installed

HP_{geni} = Total generator horsepower installed

$HP_t = HP_{shpi} + HP_{geni}$

- Propulsion Horsepower Allocation	HP_{shpi}/HP_t
- Electrical Horsepower Allocation	HP_{geni}/HP_t
	= 100% HP_t

- Tankage/Voids Volume V_{tk}/∇
  ($V_{tk} = V_{3.9}$)

- Large Space Volume V_{lo}/∇
  ($V_{lo} = V_{1.2}+V_{1.34}+V_{4.1}$)
  $V_{1.2}$ = Weapons and Ammo
  $V_{1.34}$= Aircraft Stowage
  $V_{4.1}$ = Propulsion Systems

- Arrangeable Volume V_a/∇
  ($V_a = V-V_t-V_{lo}$)

  $= 100\% \nabla$

Screen 2-6: Functional Volume Allocation Fractions
(graphical [s,c])

Since the unassigned volume may be reserved for a specific function or allocation area, rather than being a straight margin, as in weight, it will not be distributed.

- Combat Systems Volume V_{cs}/∇
  ($V_{cs} = V_1$)

- Machinery Related Volume V_{ma}/∇
  ($V_{ma} = V_4+V_{3.5}+V_{3.9}$

- Containment Volume V_c/∇
  ($V_c = V_2+V_3-V_{3.5}-V_{3.9}$)

- Unassigned Volume V_5/∇

  $=100\% \nabla$

Screen 2-7: Electrical Energy Allocation Fractions
(graphical [s,c])

NOTE: (1) follows the same classification as the Navy Standard Ships Work Breakdown Structure (SWBS) [22].

(2) Menu driven input selection:

Select:
E_t = maximum functional electric load
E_i = installed electric capacity
(90% total capacity without one generator)

- CPO Living Area per man $A_{2.12+2.212}/M_{acpo}$ ft^2/man

- Enlisted Living Area per man $A_{2.13+2.213}/M_{aenl}$ ft^2/man

- Officer Ship Size Ratio M_{aoff}/Δ_{fl} men/1Kton

- CPO Ship Size Ratio M_{acpo}/Δ_{fl} men/1Kton

- Enlisted Ship Size Ratio M_{aenl}/Δ_{fl} men/1Kton

Screen 3-13: Margin Summary (graphical [c])

Where both an aquisition and service life margin exists, both will be displayed together in a "composite" bar-graph with aquisition margin on the bottom and service life on top.

With each margin index, a third bar-graph will display the expected NAVSEA standard value.

- Weight[29]

  Symbol: Δ_{al} = architecural weight limit

  * Acquisition Margin $W_m/(\Delta_{ls}-W_m)$
    - NAVSEA Standard $.1 * (\Delta_{ls}-W_m)$
  * Service Life Margin $(\Delta_{al}-\Delta_{fl})/\Delta_{fl}$
    - NAVSEA Standard $.1 * \Delta_{fl}$

- KG[29]

  Symbol: KG_{al} = KG Architectural limit

  * Acquisition Margin KG_m/KG_{ls}
    - NAVSEA Standard $.1 * KG_{ls}$
  * Service Life Margin $(KG_{al}-KG_{fl})/KG_{fl}$
    - NAVSEA Standard $1.0/KG_{fl}$ = (1.0 ft KG_{fl})

- Electric Power[28]

Symbols: E_g = KW rating of one generator

E_{am} = acquisition margin

E_{slm} = service life margin
= $(.9*(E_i - E_g) - (E_t + E_{am})$

$E_m = E_{am} + E_{slm} - E_2$

* Acquisition Margin	E_{am}/E_t
- NAVSEA Standard	$.2 * E_t$
* Service Life Margin	$E_{slm}/(E_t+E_m)$
- NAVSEA Standard	$.2 * (E_t+E_m)$

- Volume

* Service Life Margin	V_5/∇
- NAVSEA Standard	0%

- Manning

* Service Life Margin	$(M_a-M_t)/M_t$
- NAVSEA Standard	$.1 * M_t$

3.5 Computer-Assisted Comparative Analysis

The methodology proposed has in excess of 200 parameters and indices available for comparison. These are grouped by type and category in 31 different screens using three levels of analysis. This has the potential of making the search for differences and impacts due to various indices difficult for the inexperienced user.

The use of a computer-assisted comparative analysis type of approach rests upon the simple proposition that the designer should use all of the significant information available about the comparative naval ship design problem. Without some type of available structure to assist the designer in organizing the multitude of possibilities, the designer tends to polarize around only a few of the causes and impacts of the differences in the design and may miss important aspects of the problem.

The analysis of comparitive naval ship design involves a very large number of alternatives and possibilities to examine. Even when they are narrowed to the 200-plus proposed, it is, in many cases, not immediately obvious what the cause and impacts of the design differences are. People have a tendency to focus on a simple, clear cut solution and tend to avoid the complicated paths. This strategy may result in a high probability of missing an important cause or impact. The computer lends itself easily to assist the designer in this manner by examining many different applicable indices and providing a listing of those indices that have resulted in a "major change" which is defined by the user as a significant percentage of change for a given group of indices. The designer has the option to change this percentage at any time by the use of a "control" key.

This section proposes the implementation of an effective technique for assisting the designer in his analysis.

3.5.1 User Interface Methodology

The proposed method is that of a "decision tree" type analysis. A "decision tree" is a conceptual device for displaying a group of possible decisions that can be made. The choice is then up to the user or designer. In the comparative analysis adaptation, the user is presented with a group of differences or impacts that are the result or cause of the indice he is investigating. The user must then decide which of these new indices he now wishes to investigate further. Subsequent investigations result in the same type of display, supplying the user with related indices that are scanned by the analysis program for a "major change". Although these indices could be examined manually by the designer by shifting through several applicable screens, the computer's speed allows it to rapidly scan all the selected indices and provide all the differences on one "Comparative Analysis" screen as shown in figure 3.4. In the event that all indices will not fit on one screen, the screen will prompt the user with the number of pages of data available and a "control" key will allow the user to change to any page desired. The user may additionally exercise the option to print the differences to a file. The output file will be structured similar to the screen displayed as figure 3.4.

Some comparisons are easily performed without the aid of the analysis module, either due to designer experience or a simple technology change with obvious results. The user, therefore, must select the comparative analysis module as an option.

To enter the comparative analysis option, the user must select the indice for examination from those available on the screen. The exact method of selection and option execution will be left to the programmer. Upon selection of the indice and option, the user will be prompted for a "major change" percentage. All analysis indices with differences less than this percentage will not be displayed. Since the option will exist to allow the user to change this percentage at any time using a "control" key, it is recommended that the user first select the default value of 0% to view all results and then change the percentage to eliminate what he does not desire to see. This will ensure that all information is viewed at least once. When the user has completed his analysis of the "Comparative Analysis" screen, he must decide which screen he desires to go to next. Each indice is displayed with its respective screen number to assist him. The appropriate "control" key will select the next screen. The user may now again select the comparative analysis option for an indice on the new screen thus repeating the process until he has completed his analysis to his satisfaction.

The actual flow chart for this module will be presented in section 3.6.

COMPARATIVE ANALYSIS

B = TECH BASE
V = IRGT VAR

Screen	Indice	B	V	Delta
1-1	Full Load Displacement	5537.3	5328.5	-3.8%
1-1	Total Enclosed Volume	658110.0	650232.0	-1.2%
2-3	FL Machinery Wt Frac	44.8%	43.0%	-7.7%
2-3	LS Machinery Wt Frac	34.7%	35.3%	2.1%
2-5	Tankage Volume Frac	9.4%	8.0%	-15.9%
2-6	Machy Func Alloc Vol Frac	37.6%	36.8%	-3.3%
2-8	Propulsion Fuel Alloc	68.0%	57.8%	-35.7%
2-10	Engr Manning Alloc Frac	16.6%	15.9%	-4.0%
2-12	Machy Func Cost Alloc	38.9%	42.1%	14.8%

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Figure 3.4 Sample Comparative Analysis Screen

3.5.2 Structure Methodology

The logical solution of a module of this type is to have the computer search "each and every" possible related indice to the one being examined. This solution, however, has several drawbacks. First, it is very time consuming for the author who is required to determine and list each indice, and for the programmer who must program the extensive logical paths that must be examined. Second, if the paths are extensive, then the program will require additional computation time to perform the checks, thus resulting in a greater waiting time for the user. Third and most important is that for some parameter differences, such as displacement or volume, the end result may be that the list of changed indices is so long that the comparative analysis only makes the analysis more complicated instead of easier.

The alternative solution, adopted for this program, was to use the three levels of analysis to create a hierarchial type of comparative analysis which only examines one step of differences at a time in a closed loop type of structure. In any given level of analysis, the comparative module option examines only the same level and the next lower lev^l and when in level three, the analysis looks only at level one. The exact methodology is explained in subsequent paragraphs.

The user may enter this option in any level of two-ship comparative analysis, while in any screen. If the user selects a level one, primary characteristic indice for comparative analysis, then the module methodology is set up to ask the following questions of the level indicated.

- Level 1: What related characteristics are affected by the difference being examined?

- Level 2: Which resources are affected by the change in level 1?

    * Weight, Volume, Energy, Manning, Cost
    * Look at functional fraction first

The methodology adopted for a Level 2, Resource Allocation, analysis asks the following questions.

- Level 2: What related resources must be examined to provide sufficient information regarding the effect of the change on level 2 resources?

- Level 3: For any given resource change, how was any related function affected?

    * Containment, Main Propulsion, Electrical, Auxiliary, Combat System, Human Support, Margin.

The level 3, functional investigation, then seeks to find the cause of the difference from level 1 primary characteristics by asking the question.

- Level 1: What could have caused the function to change?

Using the above methodology, the parameters for comparison by this option were selected and are listed in appendix F under the subheading "comparative analysis examines".

In this manner, the user will only receive the next level of information and although he does not receive all significant differences at once, it is the opinion of the author that he receives the information in a logical sequence without being overwhelmed by excess information.

3.5.3 Example Investigations

Appendices C and D are sample spreadsheet investigations performed on a microcomputer, simulating the two-ship analysis discussed in this chapter. Although no graphics are available in this type of comparison, the author has found this to be a powerful tool that can be used on almost any microcomputer with spreadsheet capability. The first section of each spreadsheet acts as a data base and lists the input parameters required. The remainder of the spreadsheet simulates, in a tabular format, the screens discussed in sections 3.2 to 3.4. It is now possible to manually use the comparative analysis paths presented in appendix F to perform an analysis on a certain aspect of the variant design.

The appendix C example simulates an analysis of ships for which a full data base would be available, and relates an existing design, the DD963 at delivery, with a new design, the DDG51. Additional discussion relating this thesis methodology to integrated data bases is included in chapter 6. It should be noted that since no central data bank facility currently exists within the Naval Sea Systems Command for any given ship, the parameters used were obtained from various sources and may not reflect the current design. Although every effort was made to obtain the most accurate information, extreme accuracy was not as important as having sufficient information to present a good example of how the two ship analysis is presented and how a comparative analysis would be performed. Sources of the information used in this analysis are included in the appendix.

Appendix D is an ASSET technology study performed by Goddard in reference (40), of a baseline technology frigate versus a variant with Inter-cooled Regenerative Gas Turbine main engines. It should be noted that parameters not supported by the Advanced Surface Ship Evaluation Tool (ASSET) are listed as "NA" in the input section. All subsequent indices impacted by the nonavailability of these parameters are listed as "NA" in their respective screens. The application of this comparative ship design model to ASSET will be discussed in greater detail in chapter 7.

To assist in the understanding of how this comparative procedure is to be implemented, two examples will be presented using the data of appendices C and D and the comparative analysis paths proposed in appendix F.

3.5.3.1 New Technology Impact Evaluation

One of the primary uses of the proposed comparative ship design model is to perform impact assessments of emerging HM&E technologies on a relatively detailed level. In this example, adapted from Goddard in reference (41), a baseline frigate was developed to perform technology impact evaluations. All tradeoffs were performed on ASSET with basic performance characteristics such as combat system selection, mobility (range, endurance), survivability and operability being held constant. Design standards and practices such as margins, stability, strength criteria and thus arrangement tightness were also held constant. The impact of the new technology would therefore become evident through changes in the ship size, characteristics and cost.

The new technology selected for this case study is the tradeoff of an Inter-cooled Regenerative Gas Turbine (IRGT) propulsion plant vice the standard LM2500-30 plant installed in the baseline. The ASSET results were placed in the simulated data bank, two-ship analysis spreadsheet of appendix D.

This example is for demonstration of the principles and concept of the methodology developed and is not intended to be a rigorous tradeoff analysis of the IRGT.

To perform a computer-assisted comparative analysis, the user would first enter the two-ship analysis section and select the baseline and variant he chooses to evaluate. He may then go freely through the available screens to analyse the differences.

Assume that while in screen 1-4, the designer chooses to investigate the impact of the BOOST ENG TYPE difference of GT vs IRGT. Upon selection, through the use of a "control" key, of the computer-assisted analysis mode, the program logic would enter the "Comparative Analysis" screen and scan automatically the related indices proposed for BOOST ENG TYPE listed in appendix F. Since the user is aware of the fact that several minor differences may occur that are not significant, he chooses to set the "major change" significant percentage at 1%, thereby preventing the display of any changes or "delta's" that are less than that value. The programmed comparative analysis option then displays the following relative differences on the screen.

Screen	Indice	B	V	Delta
1-1	Full Load Displacement	5537.3	5328.5	-3.8%
1-1	Total Enclosed Volume	658110.0	650232.0	-1.2%
2-3	FL Machinery Wt Frac	44.8%	43.0%	-7.7%
2-3	LS Machinery Wt Frac	34.7%	35.3%	2.1%
2-5	Tankage Volume Frac	9.4%	8.0%	-15.9%
2-6	Machy Func Alloc Vol Frac	37.6%	36.8%	-3.3%
2-8	Propulsion Fuel Alloc	68.0%	57.8%	-35.7%
2-10	Engr Manning Alloc Frac	16.6%	15.9%	-4.0%
2-12	Machy Func Cost Alloc	38.9%	39.6%	2.8%

The designer may then draw certain conclusion from this information:

- the desired goal of reducing displacement and volume has been achieved

- although light ship machinery weight increased, the net full load machinery weight decreased, indicating a decrease in fuel requirements.

- tankage volume and propulsion fuel allocation has shown dramatic decrease.

- cost of new machinery plant has increased.

Although this information has already provided the user with a good sense of the impact, let us assume that the user desires to find additional information on where the full load machinery weight savings originate. He would then select screen 2-3 by using a "control" key which will prompt him for the desired screen. Screen

2-3 will then be displayed and the user may select the comparative analysis option for FULL LOAD MACHY WT FRAC. The program again enters the "Comparative Analysis" screen and displays:

2-1	Main Prop Wt Frac	10.1%	10.9%	8.2%
2-1	Elec Wt Frac	5.8%	5.9%	1.1%
2-1	Aux Wt Frac	14.7%	14.8%	-1.7%
2-2	Liquid Fuel Load Frac	78.8%	74.3%	-22.1%

This verifies the previous conclusion that fuel requirements have decreased dramatically while the main propulsion weight fraction has increased. Since performance was required to remain constant, the range could not have changed, therefore the new engines must be much more fuel efficient, but heavier.

The user may now desire to investigate further the main propulsion weight fraction increase by selecting first new screen 2-1 then the comparative analysis option for MAIN PROP WT FRAC. The new screen will display:

2-11	Prop Plant Constr. Cost	8.2%	8.6%	6.6%
3-3	Prop Units Wt Frac	47.4%	52.1%	18.7%
3-3	Trans/Propel Wt Frac	29.1%	26.2%	-2.9%
3-4	Main Prop Spec Wt	18.33	19.83	8.2%
3-4	Main Prop Ship Size Ratio	9.48	9.85	3.9%
3-4	Drag/Disp Ratio (Endur)	18.30	19.83	8.2%
3-4	Drag/Disp Ratio (Sust)	60.00	63.00	5.0%
3-4	Prop Units Spec Wt	8.70	10.30	18.7%
3-4	Transm/Propel Spec Wt	5.30	5.20	-2.9%
3-4	Propul Cost/Wt Ratio	$94.76	$93.40	-1.4%

This screen confirms the increased weight fraction of the propulsion units, it shows changes in specific weights of propulsion related items and actually shows a slight decrease in the propulsion plant cost to weight ratio. It additionally provides the user with an increased drag/displacement ratio which may be attributed to a variant hull form change. The new hull form may have a worse set of shape characteristics or an increased displacement to length ratio. The user may make a mental note and investigate this later.

To demonstrate the "closed loop" effect of this method of analysis, the example will continue under the assumption that the user may have started his analysis on this screen and desires to find a cause or reason for the large change in propulsion units specific weight. He would then go to screen 3-3 and select the comparative analysis option for PROP UNITS SPEC WT, which will provide him with the following level one information:

1-3	Max Sustained Spd	27.9	27.5	-1.4%
1-3	Max Trial Spd	29.0	28.7	-1.0%
1-3	SHP Reqd (Endurance)	9861	10064	2.1%
1-4	Boost Eng Type	GT	IRGT	*
1-4	SFC @ Endurance	.544	.343	-36.9%
1-4	SFC @ Sustained	.433	.330	-23.8%

This display provides the cause directly as being the change in the boost engine type. It also shows that the engine is drastically more efficient than the present LM2500 installed.

The user may now draw his final conclusions and recommendations regarding the IRGT tradeoff or he may continue to examine other aspects of the design, such as the decrease in sustained speed, the increase in drag/displacement ratio or the decrease in total ship volume. Using the same procedure, the designer will find that the new variant ship is shorter and beamier, resulting in the powering loss. This module will assist

CHAPTER 4

MULTI-SHIP COMPARATIVE ANALYSIS

4.1 Methodology

To provide a broader perspective than that provided in the two-ship analysis, this option allows the user to display up to six data bank ships for direct comparative analysis of a selected group of "stacked" parameters or indices. This provides the user with the ability to observe related parameters and compare them to other similar ships in the data bank. The parameters available for this type of display are limited to the most important and are discussed in section 4.2. Once this section of the program has been selected, the user may change the ships he is displaying or the parameter he has selected.

To allow for several related parameters to be grouped, the graphical display will be in a vertical "stacked" bar graph format. Figure 4.1 is an example of the displacement light ship and full load relationship. Other examples would be the "stacking" of all SWBS groups or SSCS groups.

4.2 Selected Indices

Those parameters and indices considered most useful for ship size and performance comparison were selected to be available for multi-ship comparison. To allow for a meaningful and uncluttered

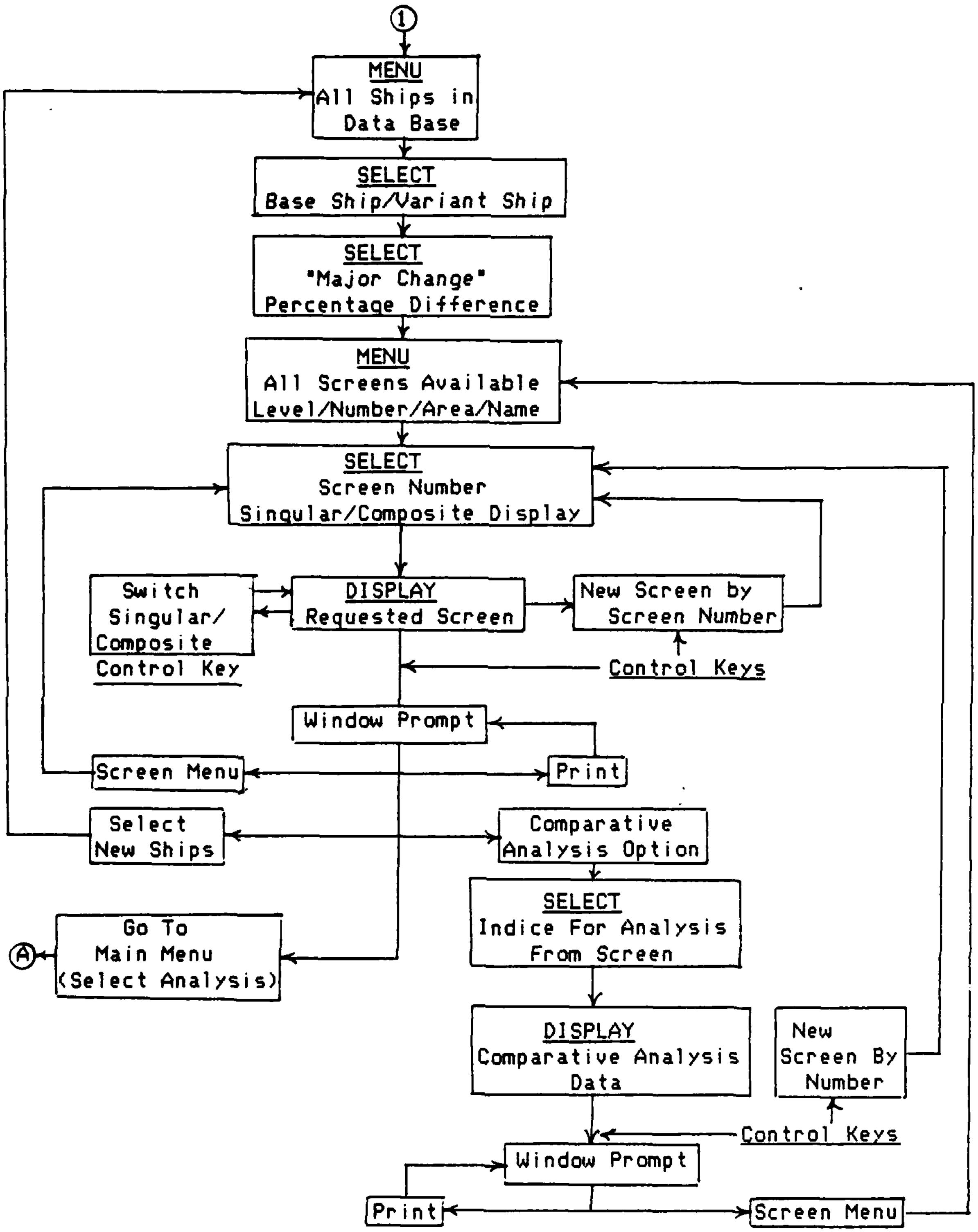


Figure 3.5 Two Ship Comparative Analysis Flow Chart

option on. The exact method of inputting the indice could be through keyboard entry, or ideally, by direct graphic screen interaction. The detailed implementation is left to the programmer. Used in two-ship analysis section only.

When providing the full "SCREEN MENU" for the user to make a selection, it should be complete enough to ensure he understands what information is available. This should include the name of the level that the screen is in (i.e. Primary Characteristics), the screen number (i.e. 1-1,1-3), used also for direct selection, the area that the screen pertains to (i.e. weight, volume, containment, etc), as discussed in section 3.1, and the name of the screen.

A detailed definition and significance of each of the suggested indices, along with the applicable equation and suggested comparative analysis paths, are available in appendix F to assist the programmer and the user.

Since the user may not have all available parameters to input, the programmer must ensure that the program will continue to function if parameters are missing. A check loop, is therefore necessary to ensure that "divide by zero" problems do not occur. The program should instead provide a statement of non-applicability for any indice that cannot be calculated due to lack of information.

All other sections of the flow chart are either self explanatory or are explained in detail in sections 3.1 to 3.5.

Window Prompt Menu Key - provides the user a menu of all available exit options from the particular module that he is accessing. Options are all possible paths out of the "window prompt", as displayed in the appropriate flow chart. Used in all modules.

New Screen Key - user may select next screen directly either by system prompt or by typing in the new screen number with the control key. Exact implementation left to the programmer. Used in Two-ship analysis section only.

Switch Singular/Composite Key - allows user to shift his screen from singular to composite display or vice versa, as explained in section 3.1. Pertains to two-ship analysis option only.

"Major Change" Percentage Key - Prompts the user to enter the new percentage that he considers to be a major change. In the regular screens of the two-ship analysis, any difference, or "delta" greater than this percentage will be highlighted in reverse video. For the "comparative analysis" option screen, only indices with differences greater than this percentage will be displayed. If no selection is made, the default value will be zero, to allow all indices of the selected screen to be displayed. Pertains to two-ship analysis option only.

"Comparative Analysis" Key - prompts the user directly for the indice he wishes to perform a comparative analysis investigation to identify a "culprit" in a crime. The objective in this comparative methodology is to identify differences in completed ship designs and then to determine the causes and effects of these differences. This helps the designer to better understand their design practices and standars.

3.6 Programming Notes

Figure 3.5 illustrates the flow chart to be used for this section of the overall program methodology. Examples of several individual paths have been discussed in detail in previous sections of this chapter and require little further explanation. The examples of section 3.5 show how the overall comparative analysis section interfaces with the module.

There are, however, several "control" keys which are referred to in the text of the examples. These will be further explained to ensure the programmer understands all possible exit paths used by these keys. A "control" key is, by definition, any key or combination of keys that will result in some action on the screen, either directly, or by opening a "window" type prompt for user decision. Some of the possible paths for the "control" keys are displayed on figure 3.5. Listed below is a summary of all required keys, some of which will be used in other sections of the program.

Data Base Access Key - provides the user the ability to directly query the data base in use. Should be available in all sections of the program.

The analysis above partially goes full circle to again provide the user with information on how the difference in the weight may have impacted the ship size. The reason for the significantly larger beam could be explained by the much heavier deckhouse and the heavier weight in turn is caused by the selection of steel vice aluminum as the deckhouse structural material.

It should be clear from the short example above, that as the user goes through his analysis, he will continue to find other interesting aspects of the variant design in relation to the baseline. If this were incorporated in a computer program as a computer-assisted module, the analysis could be performed more rapidly and more efficiently. Additionally, the graphics capability would more dramatically highlight the differences. It is obvious at this point that there are many more analysis that could be performed on a data base of this type.

The author again cautions the reader that the data used in the study is notional and may not reflect the actual designs. It is the methodology development that is most important and no verification was made of any data obtained.

3.5.4 *Comparative Analysis Conclusion*

It should be noted that as the analysis paths suggested in appendix F are explained by different users, more efficient investigative paths will be identified. An analogy can be made to a detective looking for clues in order to piece together a logical

		B	V	DELTA
2-11	Hull Structure Cost Frac	5.5%	3.3%	-38.1%
3-1	Shell & Supports Wt Frac	34.6%	29.4%	-19.3%
3-1	Hull Bkhds/Decks Wt Frac	37.1%	36.9%	-5.4%
3-1	Deckhouse Wt Frac	6.3%	9.1%	35.9%
3-1	Foundations Wt Frac	9.6%	11.6%	14.3%
3-1	Other Struc Wt Frac	12.3%	13.1%	1.4%
3-2	Hull Struc Spec Wt	6.65	6.76	1.7%
3-2	Basic Hull Struc Density	6.40	5.50	-13.1%
3-2	Deckhouse Struc Density	1.70	3.20	91.8%
3-2	Foundations Wt Frac	13.0%	13.1%	14.3%
3-2	Containment Cost/Wt Ratio	$54.40	$45.98	-15.5%

This confirms that the hull structure is considerably more efficient and weight is saved in the basic hull. The deckhouse weight and its corresponding structural density has, however, increased noticeably. Assume the user desires to investigate further the differences in the deckhouse. Selection of screen 3-1 and comparative analysis for DECKHOUSE WT FRAC will result in the following "Comparative Analysis" screen.

		B	V	DELTA
1-1	Full Load Displacement	7828.6	8446.0	7.9%
1-1	Light Ship Displacement	5852.9	6592.0	12.6%
1-1	Total Enclosed Volume	1037193.0	970663.0	-6.4%
1-1	Ship Density Full Load	16.9	19.5	15.3%
1-1	Ship Density Light Ship	12.6	15.2	20.3%
1-1	Length Between Perp.	529.0	466.0	-11.9%
1-1	Length Overall	563.0	504.0	-10.5%
1-1	Beam at Waterline	55.0	59.0	7.3%
1-1	Beam (max at deckedge)	55.0	66.9	21.6%
1-1	Draft (max)	18.0	20.0	11.1%
1-3	Fragmentation			*
1-3	NBC			*
1-3	Noise Signature			*
1-3	Radar Signature			*
1-4	Deckhouse Materials	Alum	HTS	
1-4	Hull Frame Type/Spacing	long/27in	long/26in	
1-4	DKhs Frame Type/Spacing	long/27in	long/26in	

3-4	Main Prop Ship Size Ratio	10.22	11.84	15.9%
3-4	Main Prop Density	9.81	8.99	-8.3%
3-4	Prop Units Spec Wt	2.95	2.14	-27.4%
3-4	Trans/Propel Spec Wt	10.32	9.19	-11.0%
3-4	Prop Sup Fluids Spec Wt	8.03	4.88	-39.2%
3-4	Prop KW/Wt Ratio	.55	.68	24.0%
3-4	Prop Cost/Wt Ratio	$55.63	$68.74	23.6%

Since the propulsion units weight fraction and specific weight both decreased, it is obvious that a higher power density prime mover was used to achieve the additional horsepower with less weight and space allocation. In fact, if the user investigates further he will find that both ships use the same LM2500 engine, except that the DDG51 has a power upgrade from 21500 HP to 26250 HP. This higher power density (power installed relative to its weight) of the propulsion plant helps explain the higher cost of the propulsion plant.

Assume now that the user has assimilated all the information he desires about the propulsion plant at this point and wants to investigate the containment feature. If he does not remember the screen number that contains the SWBS Weight Fractions, he can use a "control" key to call up a window prompt which offer the selection of printing the information on the screen or returning to the screen menu. Upon selecting the screen menu option, he could now request to view screen 2-1 with light ship parameters. On the display, he would note that the structural weight fractions are 52.6% and 44.5% for the DD963 and DDG51 respectfully with an absolute delta of -4.8%. The selection of the comparative analysis option for this indice would result in the following display.

- Cost has increased primarily for the combat system, as would be expected, but has decreased in the containment area indicating a possible structural savings.

The above conclusions provide several continuing paths for analysis. Only two will be explained further: the increased horsepower obtained without a proportional increase in machinery weight and volume, and the increase in containment weight despite the higher ship density and shorter length.

Investigating the propulsion power increase first, select screen 2-3 and then enter the "comparative" analysis option with the selection of FL MACHINERY WEIGHT. The analysis will display:

2-1	Main Prop Wt Frac	15.0%	13.0%	-4.9%
2-1	Electrical Wt Frac	5.9%	6.9%	36.6%
2-1	Auxiliary Wt Frac	14.6%	14.2%	7.0%
2-2	Liquid Load Wt Frac	87.8%	78.5%	-13.0%

This indicates that the main propulsion weight fraction has actually decreased instead of the expected increase. Since the range is less, the liquid fuel weight decrease is anticipated. The electrical weight and auxiliary weight increases are significant and the user may desire to investigate them later. Assume the user desires to continue his main propulsion investigation. He then selects screen 2-1 and the comparative analysis option for MAIN PROP WT FRAC which displays.

2-11	Prop Constr. Cost Frac	8.6%	9.9%	17.5%
3-3	Prop Units Wt Frac	13.9%	13.2%	-9.3%
3-3	Transm/Propel Wt Frac	48.5%	56.7%	11.2%
3-3	Prop Support Wt Frac	37.7%	30.1%	-24.0%
3-4	Main Prop Spec Wt	21.31	16.21	-23.9%

- An interesting weight aspect is that it has already been shown that the DDG51 has 25% higher installed shaft horsepower, yet there is only a slight net increase in machinery weight. Contrarily, there is not the expected decrease in containment weight that would normally be expected with a high ship density and short length relative to its displacement. The user would want to explore both of these anomalies.

- Because of the method of calculating and displaying the "delta" value, as explained in section 3.1, it can be seen that propulsion horsepower and fuel allocations support the increased absolute shaft horsepower installed. The electric plant also shows a significant increase in allocation, which appears reasonably consistent.

- All volume areas show a proportional absolute volume decrease, thereby supporting the higher ship density of screen 1-1. Again this points out some areas for further investigation. The higher combat systems weight but lower volume would indicate a significantly higher combat systems density and the lower machinery volume is inconsistent with the large increase in installed power.

- Some increase in crew manning is evident, which appears inconsistent with the lower absolute containment volume.

2-8	Propulsion Fuel Alloc	80.9%	78.5%	20.5%
2-8	Electrical Fuel Alloc	19.1%	21.5%	40.2%
2-9	CPO Ratio	6.7%	6.2%	5.0%
2-9	Crew Ratio	77.0%	78.2%	14.7%
2-9	Manning Margin	8.7%	8.8%	15.4%
2-12	Combat Sys Cost Frac	35.2%	40.8%	27.5%
2-12	Machinery Cost Frac	44.5%	42.6%	5.1%
2-12	Containment Cost Frac	18.1%	14.5%	-11.5%

Although this appears to be a tremendous amount of information, it is essentially an overview of the cause and effect of the displacement change. It should again be noted that the cost figures displayed are not intended to be the actual cost figures and are used only to aid in the explanation of the methodology. This is one of the largest comparative analysis screens in this type of an analysis allowing several conclusions to be drawn from the information obtained above.

- DDG51 is shorter and beamier with greater draft explaining the need for the increased horsepower even at the lower maximum speed. This indicates a less efficient hullform.

- Although the displacement is greater, there is a net decrease in total enclosed volume resulting in the higher ship density indicated. This in turn should hold the volume driven functional weights such as structures, auxiliary and outfitting.

- The primary increase in weight appears to be due to the combat system installed.

however a known fact that the DD963 has a higher trial speed and if it were available in the data base, it would have been displayed.

The user may now desire to determine the effects of, and reasons for, the increase in displacement. He first selects screen 1-1 by using the screen call "control" key and then selects the comparative analysis option for FULL LOAD DISPLACEMENT, which presents the following information on a multi-page screen.

1-1	Basic Construction Cost	490404.0	500358.0	2.0%
1-1	Combat Sytem GFE cost	219272.0	292451.0	33.4%
1-1	Other Costs	144668.0	147605.0	2.0%
1-1	Total Ship cost	873961.0	960430.0	9.9%
1-1	Full Load Displacement	7828.6	8446.0	7.9%
1-1	Light Ship Displacement	5852.9	6592.0	12.6%
1-1	Total Enclosed Volume	1037193.0	970663.0	-6.4%
1-1	Ship Density Full Load	16.9	19.5	15.3%
1-1	Ship Density Light Ship	12.6	15.2	20.3%
1-1	Length Between Perp.	529.0	466.0	-11.9%
1-1	Length Overall	563.0	504.0	-10.5%
1-1	Beam at Waterline	55.0	59.0	7.3%
1-1	Beam (max at deckedge)	55.0	66.9	21.6%
1-1	Draft (max)	18.0	20.0	11.1%
1-2	Displacement/Length rat.	52.9	83.5	57.8%
1-2	Prismatic Coeff	.570	.604	6.0%
1-2	Waterplane Coeff	.724	.780	7.7%
1-2	Length/Beam ratio	9.62	7.90	-17.9%
1-2	Length/Draft ratio	29.39	23.30	-20.7%
1-2	Beam/Draft ratio	3.06	2.95	-3.5%
1-2	Draft/Depth ratio	.43	.48	11.6%
1-2	Length/Depth ratio	12.60	11.15	-11.5%
2-3	FL Combat Sys Weight Frac	7.6%	11.0%	56.5%
2-3	FL Machinery Weight Frac	44.5%	42.1%	2.1%
2-3	FL Containment Weight Frac	47.6%	46.9%	6.3%
2-6	Combat Sys Volume Frac	22.2%	22.3%	-6.0%
2-6	Machinery Volume Frac	42.0%	41.7%	-4.9%
2-6	Containment Volume Frac	38.5%	39.9%	-5.3%
2-6	Unassigned Volume Frac	1.3%	.4%	-90.3%
2-8	Propulsion HP Alloc	90.3%	87.7%	25.0%
2-8	Electrical HP Alloc	9.7%	12.3%	63.7%

DISPLACEMENT TO LENGTH RATIO difference of +57.8%. Upon selection, through the use of a "control" key, of the computer-assisted analysis mode, the program logic would enter the "Comparative Analysis" screen and scan automatically the related indices proposed for the DISPLACEMENT TO LENGTH RATIO indice listed in appendix F. Since the user is aware of the fact that several minor differences may occur that are not significant, he chooses to set the "major change" significant percentage at 1%, thereby preventing the display of any changes or "delta's" that are less than that value. The programmed comparative analysis option then displays the following relative differences on the screen.

Screen	Indice	B	V	Delta
1-1	Length Between Perp.	529.0	466.0	-11.9%
1-1	Full Load Displacement	7828.6	8446.0	7.9%
1-3	Range at Endurance Spd			-25.0%
1-3	Endurance Period (Fuel)			-33.0%
1-3	Shaft Horsepower Avail	80000.0	100000.0	25.0%
1-3	Shaft Horsepower (Endur)	16000.0	16800.0	5.0%
1-3	Shaft Horsepower (Sust)	64000.0	80000.0	25.0%
1-3	Drag (Sust)			34.4%

The conclusions drawn are that both direct drivers, displacement and length, contributed to the increased ratio. Additionally, since this ratio is used as a powering indicator, it is evident that the resistance has increased dramatically resulting in the need for the higher shaft horsepower installed. The range is also 25% less than that of the DD963. Although speed is one of the search parameters, it is not displayed on the screen because it is not listed in this study due to security considerations. It is, the designer until he has completed the tradeoff analysis to his satisfaction.

Using the data of appendix C and the comparative analysis paths proposed in appendix F, the reader may choose to continue the investigation for his own edification.

3.5.3.2 DDG51 Comparison to DD963

Another use of the methodology developed is the detailed comparison of a new ship design to an existing ship. This example will investigate the effects of the unusual displacement to length ratio of the DDG51 as compared to the DD963. This is only one of many comparisons that could be performed using even the simplest method of spreadsheet analysis of appendix C. Again, a manual comparison will be performed using the suggested "comparative analysis" paths listed in appendix F. The reader should by now have an appreciation for the capability of a computer program to do this analysis automatically, rather than manually. Yet, the assistance that can be provided by appendix F is both helpful and meaningful in any analysis performed.

Again, the intent of this analysis is to demonstrate the application of the "comparative analysis" path in a real situation without actually performing an extremely rigorous analysis. All references to screens and indice values are from appendix C.

Assume that the user is in screen 1-2 of appendix C and selects the "comparative analysis" option to investigate the

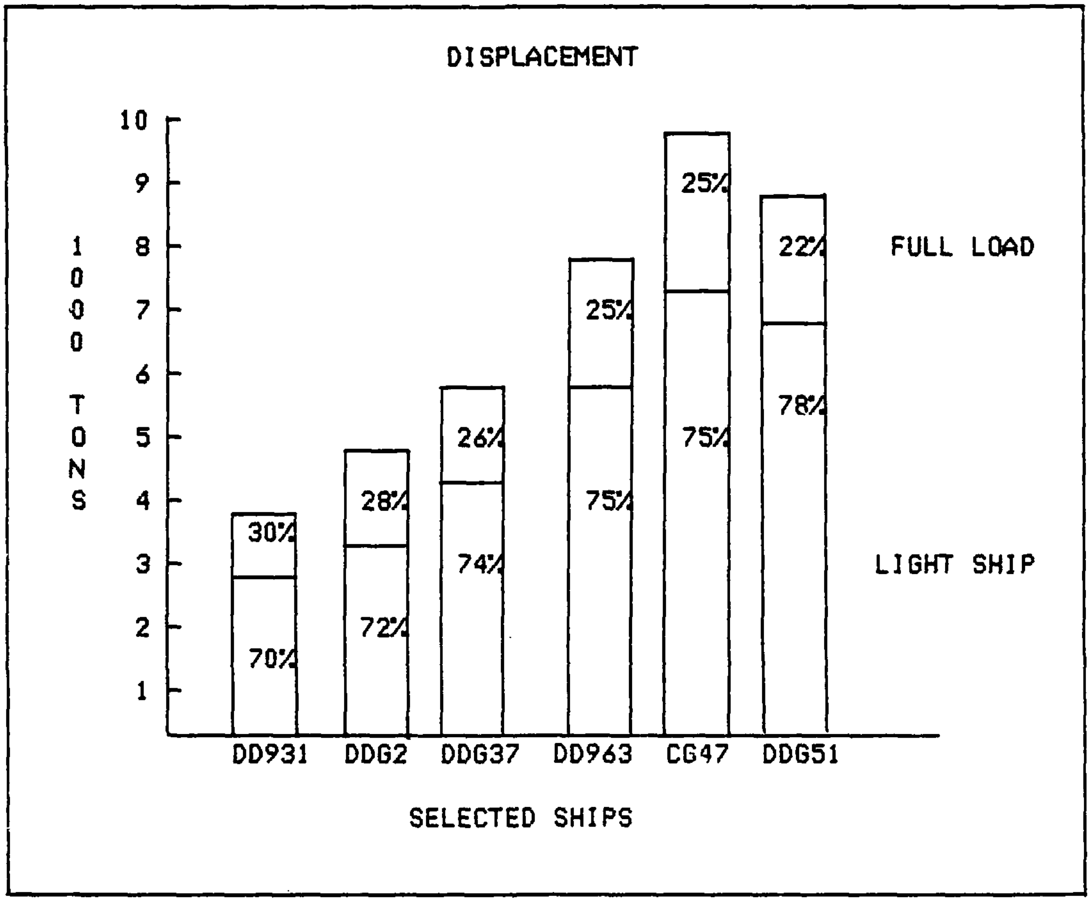


Figure 4.1 Example Mult-Ship Plot (Displacement)

display with sufficient space for necessary text, a maximum of six ships may be selected from the data base.

Each of the available indices are listed below with a short explanation of what parameters are included in the display. The same basic display methodology developed in section 3.1 will be used in this section. The Y-axis will display only absolute values of the primary parameter or whole indice. In the case where the indice is a percentage, the percent value will be placed inside the bar as shown in figure 4.1. The computer will determine the maximum value of the selected ships for the indice selected and scale the Y-axis accordingly. The number in parenthesis following each indice is its origin screen, added for reference only.

- Displacement (1-1)

  Stacked bar graph with light ship and load.

- Total Enclosed Volume (1-1, 2-5)

  Stacked bar graph with hull and deckhouse volumes.

- Ship Density (1-1)

  Select either light ship or full load.

- SWBS Weight Fraction (Full Load) (2-1, 2-2)

  Stacked bar graph with seven SWBS groups, acquisition margin and load weight.

- Functional Weight Fraction (2-3)

  Select either light ship or full load.

  Stacked bar graph with combat system, machinery, and containment weight percentages.

- SSCS Volume Fraction (2-4)

  Stacked bar graph with all five SSCS volumes.

- Functional Volume Allocation Fraction (2-6)

  Stacked bar graph with combat system, machinery, containment and unassigned volume percentages.

- Electrical Energy Allocation Fractions (2-7)

  Same selections as in screen 2-7.

  Stacked bar graph with all electrical groups and acquisition margin.

- Speed (1-3)

  Stacked bar graph showing endurance, sustained and trial speeds.

- Range (1-3)

  Single bar graph with endurance range.

- Fuel Usage Allocaction Fraction (2-8)

  Stacked bar graph with propulsion and electrical fuel allocation percentages.

- Horsepower (1-3)

  Stacked bar graph showing required endurance horsepower, required sustained horsepower, total installed horsepower.

- Displacement to Length Ratio (1-2)

  Single bar graph with displacement to length ratio.

- **Length Between Perpendiculars / Length Overall (1-1)**

  Stacked bar graph with Length overall on top of length between perpendiculars.

- **Length to Beam Ratio (1-1)**

  Single bar graph with length to beam ratio.

Although there are many other indices that could be selected for this type of analysis, the author chose to select these as among the most important.

4.3 Programming Notes

Figure 4.2 illustrates the general flow path for this section of the program. Upon selection of the multi-ship comparison option, the user will be prompted to select up to six ships from a displayed list of ships available in the data bank. Upon selection of the ships, a menu will be displayed listing all indices available to be viewed. This menu should correspond with the selected indices of section 4.2.

After the data has been displayed, the user should be able to select a "control" key which will open a window on the screen and prompt him to select either:

- select new ships
- select new parameter
- print screen
- return to main menu (select analysis type)

The program will then branch accordingly.

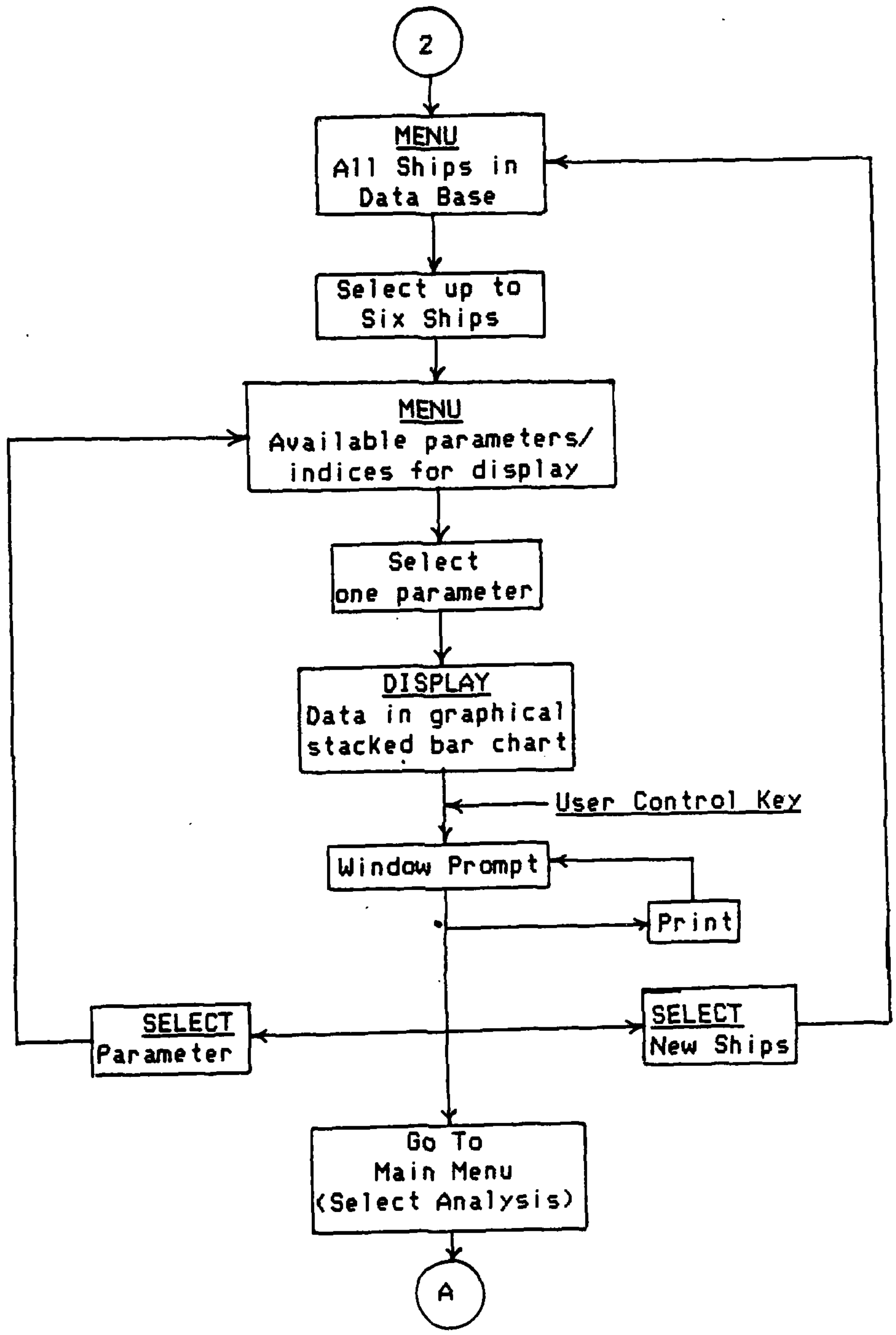


Figure 4.2 Multi-Ship Comparative Analysis Flow Chart

CHAPTER 5

TREND COMPARATIVE ANALYSIS

Methodology

The trend analysis option path provides the user the ability to plot his new or variant design and compare it directly to existing and past ships of the fleet. These plots may be in the form of "time history" or "triple plots" which are explained, along with the available indices, in sections 5.2 and 5.3.

The trend analysis will allow the user to compare his design to any combination of pre-plotted frigates, destroyers, or cruisers. If the user is designing a frigate, he may choose to see only the trend established by previous frigates, or he may choose to have his design plotted along with all available combatants. The ships selected to provide the initial trend data are:

FRIGATES	DESTROYERS	CRUISERS
FF-1006	DD-692	CG-26
FF-1033	DD-931	CG-47
FF-1037	DD-963	
FF-1040	DDG-2	
FF-1052	DDG-37	
FFG-7	DDG-993	
	DDG-51	

The trend analysis data base required to incorporate these trends into the computer program is included as Appendix E. Further ships may be included at a later date or prior to implementation, if desired.

During any trend analysis, each class of combatants will be plotted with a unique symbol, including a separate unique symbol for the new ship being compared. Examples of this are included in section 5.2.

At anytime during the execution of this option, the user should have the ability to change the trend plot he is viewing or select a new ship from the data bank.

5.2 Time History Trends

A simple graph showing the commissioning year on the x-axis versus the selected indice on the y-axis, scaled by the computer to provide the largest viewing area for the class or classes of ships selected. The initial setup will be to use the years 1940 to 2000 to allow the plotting of a range of ships from post-World War II combatants to ships scheduled to be commissioned in the near future. The user may then plot his new ship to receive an immediate graphical interpretation of how his ship fits into the current trend.

The time trends considered to be most important for this type of analysis are based on those selected in references (12) and (13), which include:

(numbers in parenthesis indicate two-ship analysis screen where the indice may be found for further explanation in Appendix F)

- Displacement Full Load (1-1)

  Y-axis: 1000 tons

- Total Enclosed Volume (1-1)

  Y-axis: 1000 ft^3

- Ship Density (Full Load) (1-1)

  Y-axis: lbs/ft^3

- Combat Systems Weight Fraction (Full Load) (2-3)

  Y-axis: percent

- Main Propulsion Ship Size Ratio (3-4)

  Y-axis: HP/Ton (SHP/ $_{fl}$)

- Electrical Capacity Ship Size Ratio (3-6)

  Y-axis: KW/Ton (KW/ $_{fl}$)

- Human Support Specific Volume (3-12)

  Y-axis: ft^3/man (V_2/M_a)

Figures 5.1 through 5.4 show examples of how the graphs for this option should be portrayed and how they may be used. The new ship plotted in reference to the overall time trend is the new technology baseline frigate of appendix D developed in a separate thesis on technology assessment, reference (40). In figure 5.1, it is noted that the new frigate follows the general frigate trend, with the exception of the downturn created by the weight constrained FFG-7 class. Figure 5.2 shows the same result for volume trend. In figure 5.3, only the frigate type of ship is plotted as a comparison and clearly shows a variance from the past decreasing ship density trend of frigates. Additionally, figure

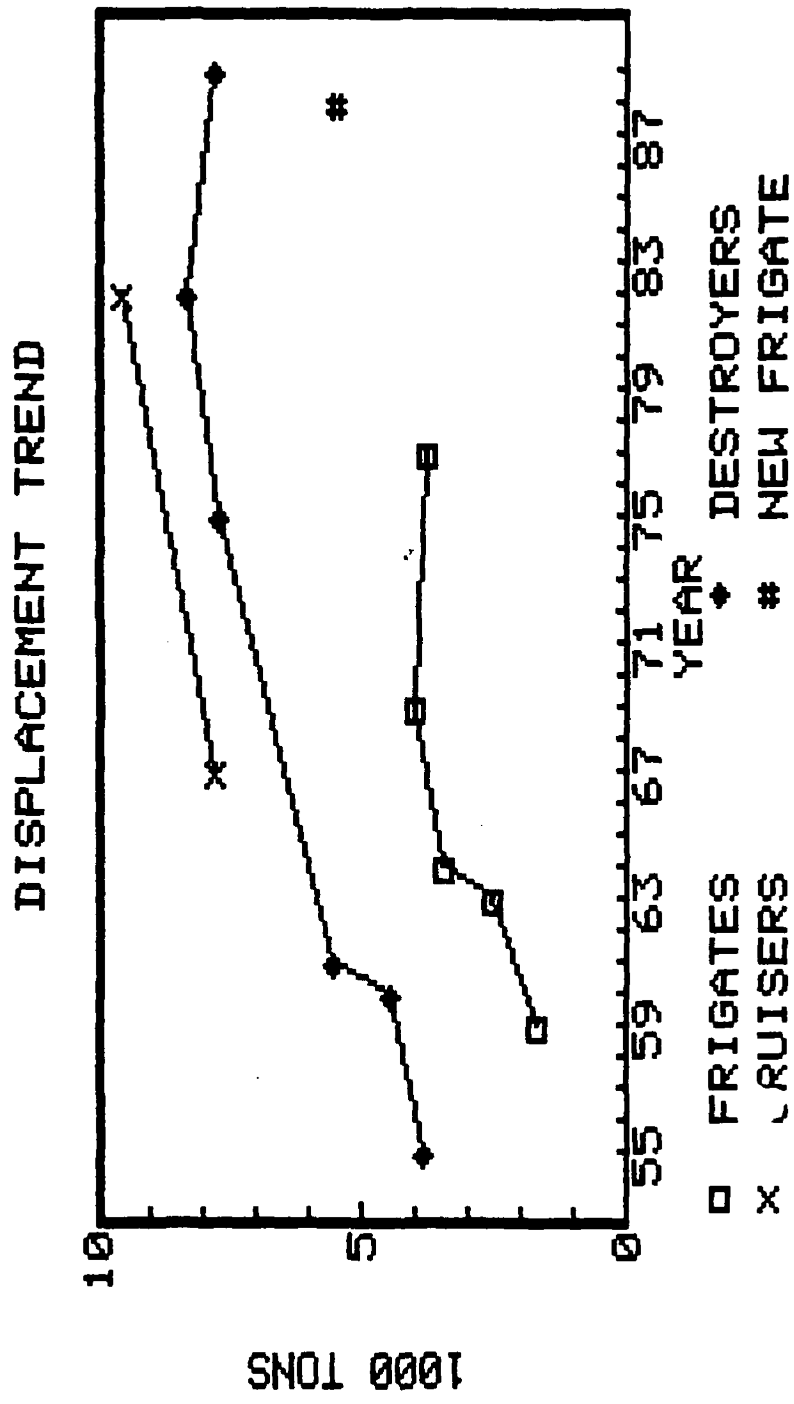


Figure 5.1 Example Displacement Trend Analysis

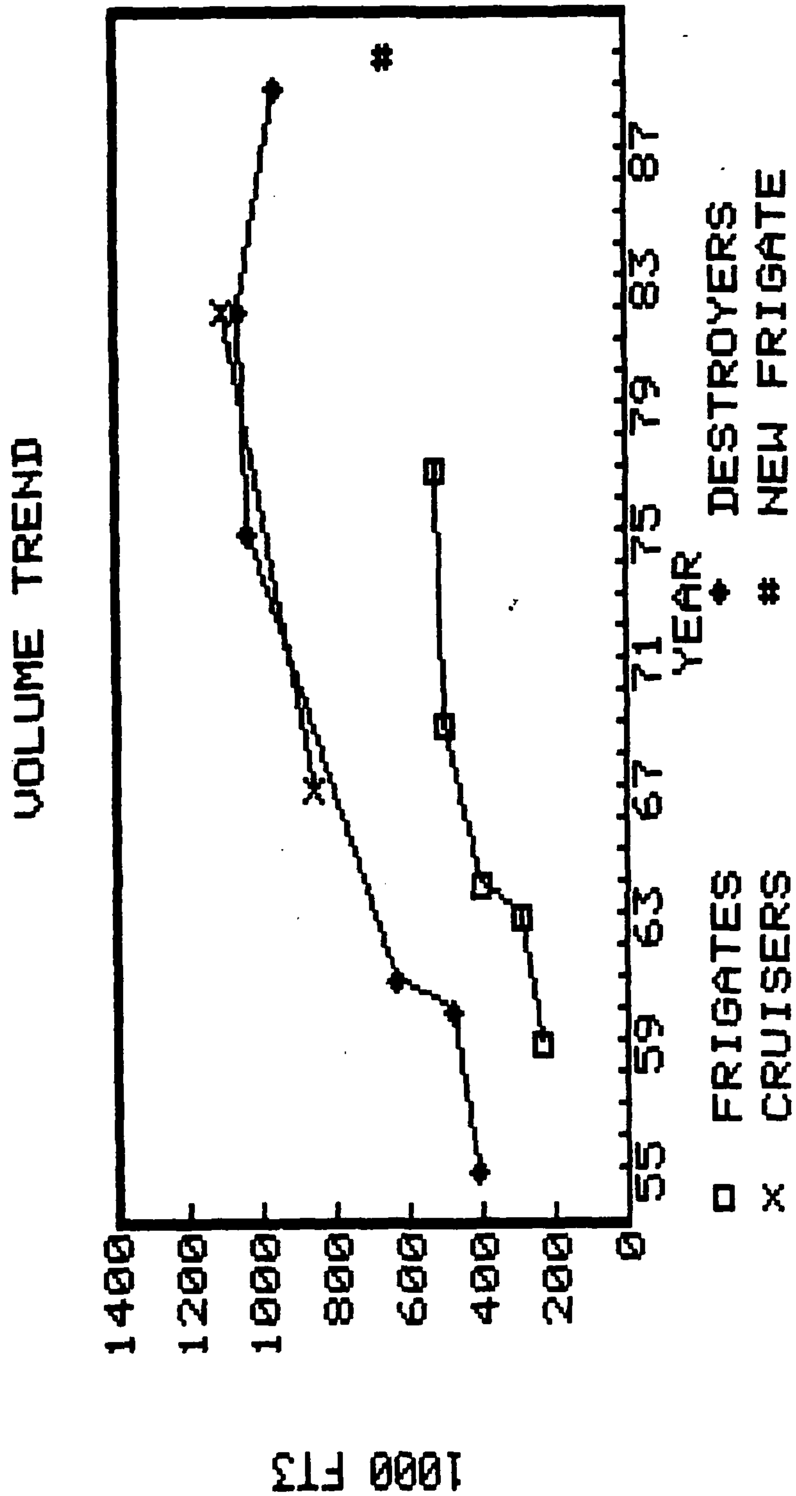


Figure 5.2 Example Volume Trend Analysis

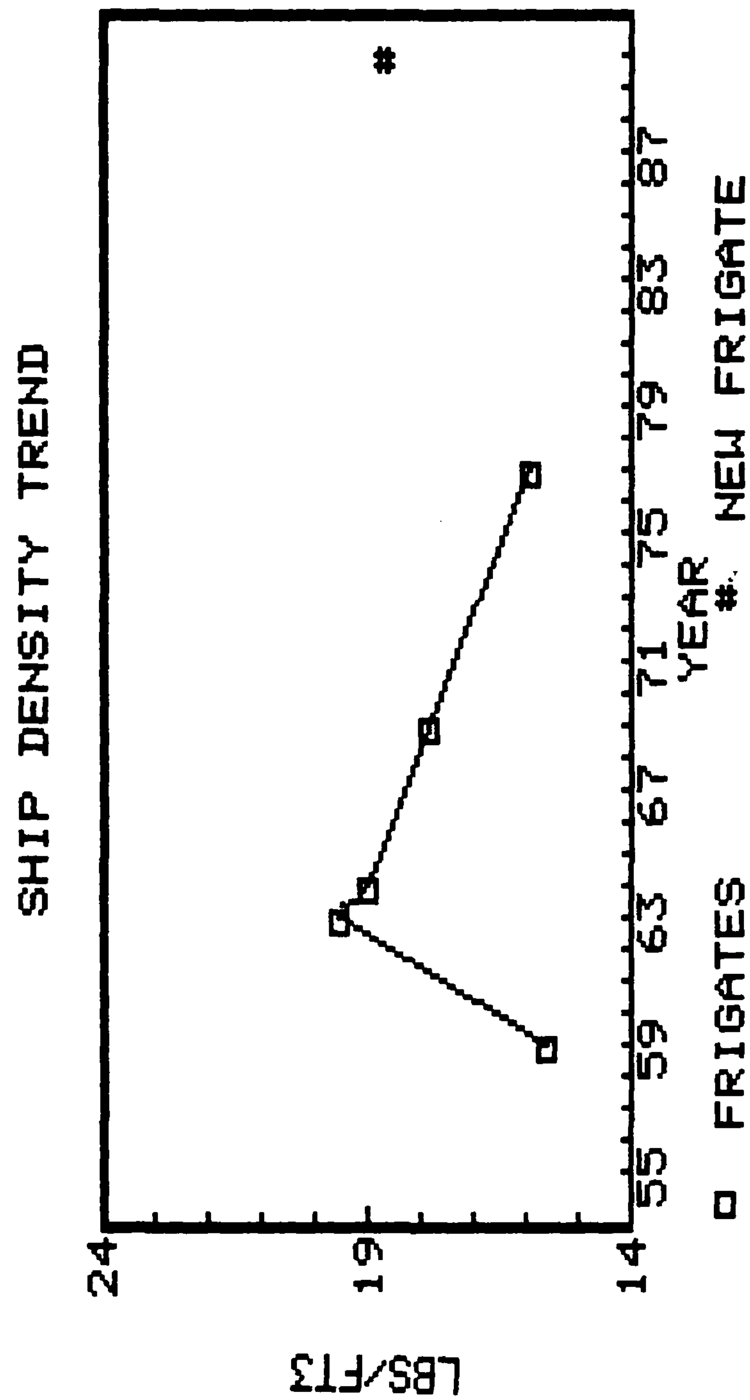


Figure 5.3 Example Ship Density Trend Analysis Selecting Only One Type of Ship For Comparison

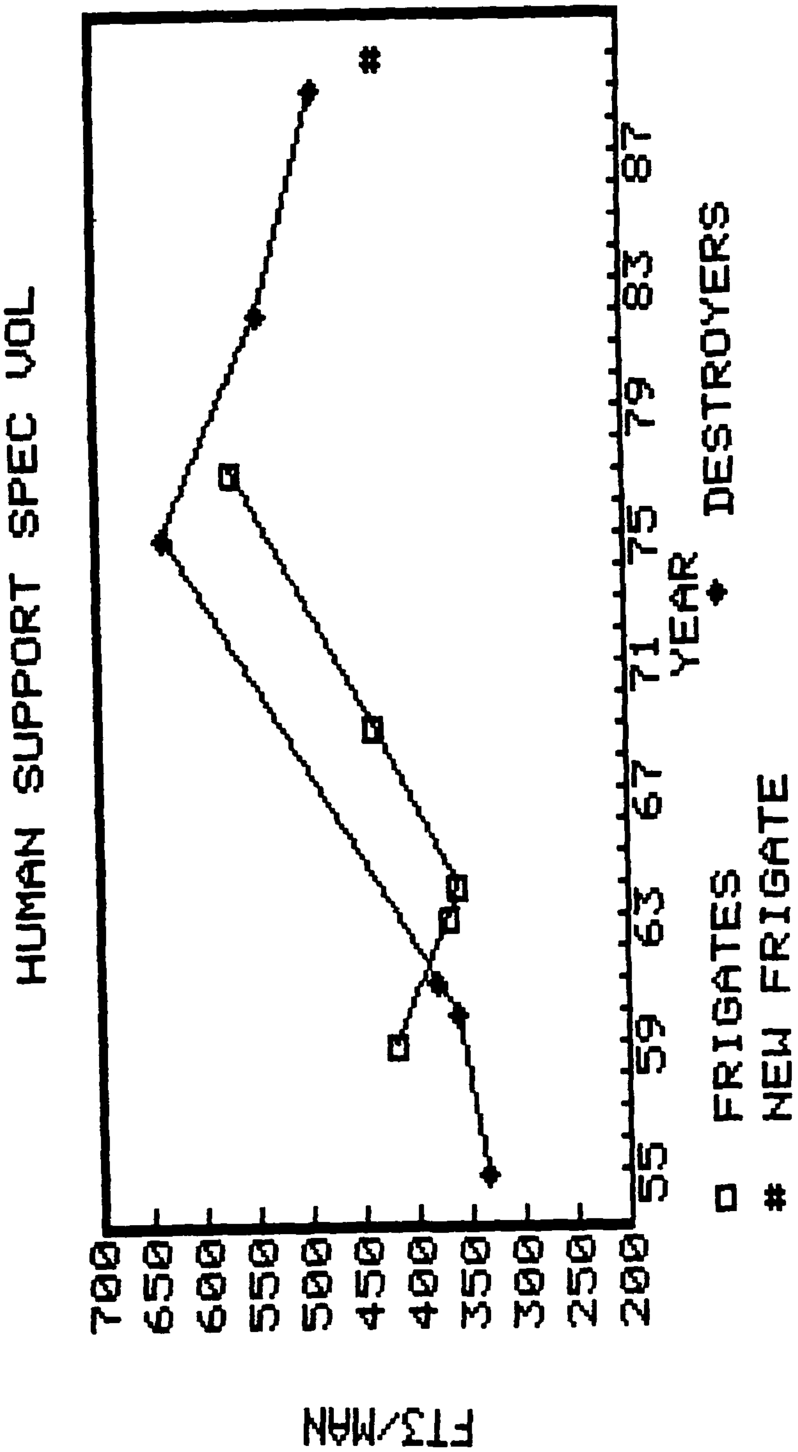


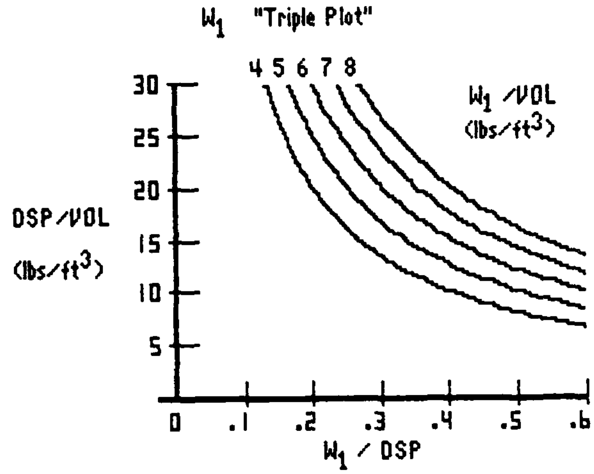
Figure 5.4 Example Human Support Trend Analysis Selecting
Two Types of Ships for Comparison

5.4, which plots the new ship with both frigate and destroyer trends for human support specific volume, shows that the new frigate is following more of a destroyer trend than that of a frigate. The remainder of the indices could be examined by the designer in the same way, providing him with the type of information that he may need to justify his design in a historical trend sense.

5.3 "Triple-Plot" Trends

In the level 3 functional investigation of the two-ship comparative analysis, the primary "drivers" contributing to the parameters of a specific functional area are examined. In each case, these drivers may be related to each other in a triple relationship first introduced by Heller and Clark in reference (9) for the SWBS group 1 structures and expanded by Cassedy in reference (8). In this portion of the trend analysis, these drivers are graphed in relation to each other and can be compared to existing combatants of the same type or all types similar to the way the comparison was performed in section 5.2.

Figures 5.5 through 5.8 are the exact graphs that should be incorporated into the program. These graphs are based on current designs and provide sufficient overlap to include all combatant designs discussed in this thesis. All values which should be entered in the data base to be available for plotting by the user are listed in appendix E. The ships used for the initial



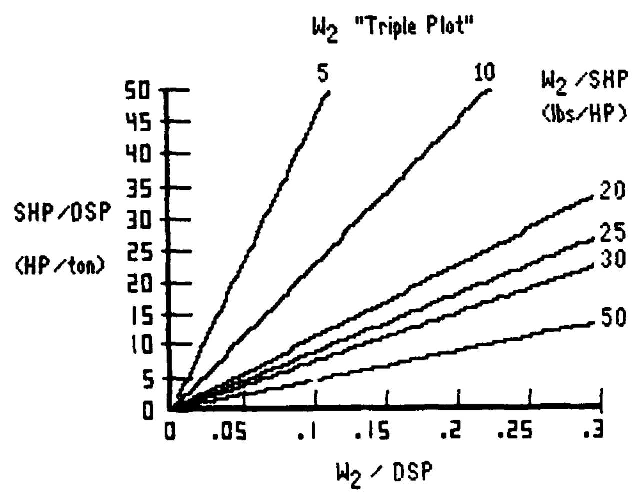


Figure 5.5 Basic "Triple Plots" W_1 and W_2

AD-A158 971 METHODOLOGY FOR COMPUTER-SUPPORTED COMPARATIVE NAVAL SHIP DESIGN VOLUME 1(U) MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN ENGINEERING U H ROWLEY JUN 85 2/2

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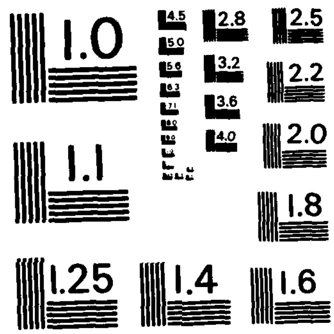
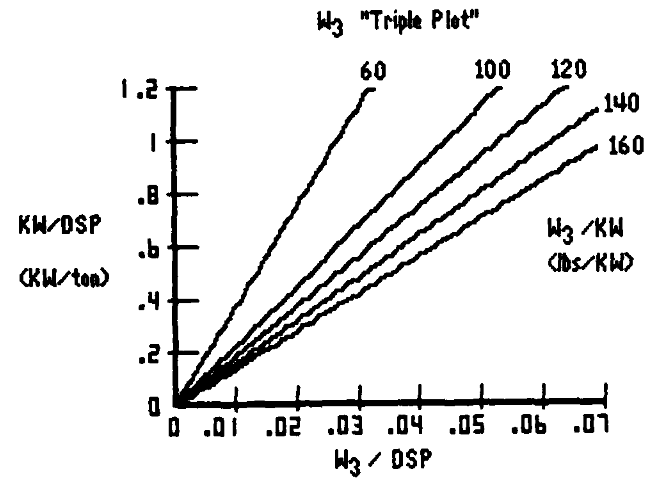


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



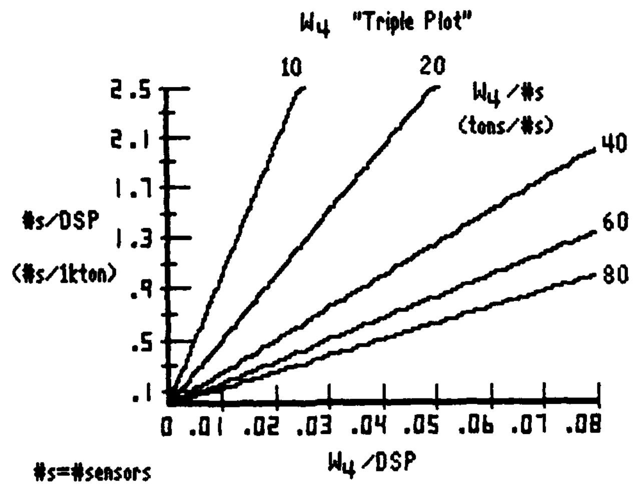
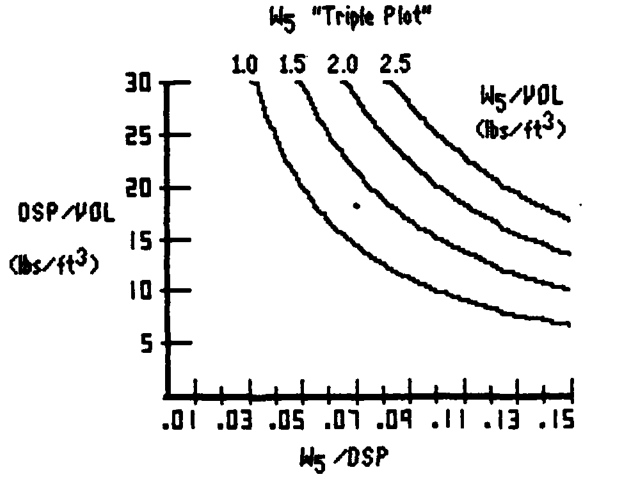


Figure 5.6 Basic "Triple Plots" W_3 and W_4



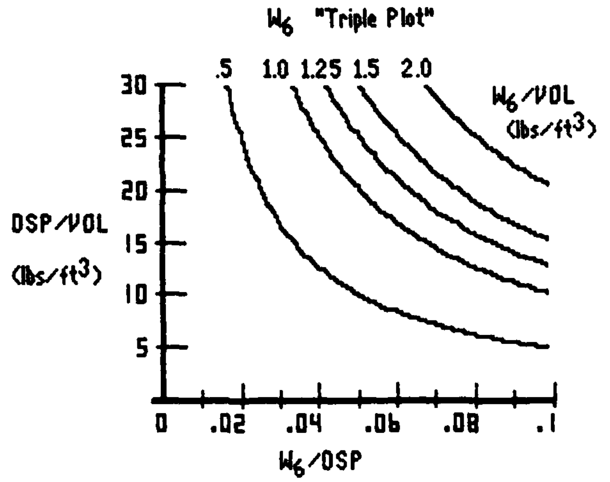


Figure 5.7 Basic "Triple Plots" W_5 and W_6

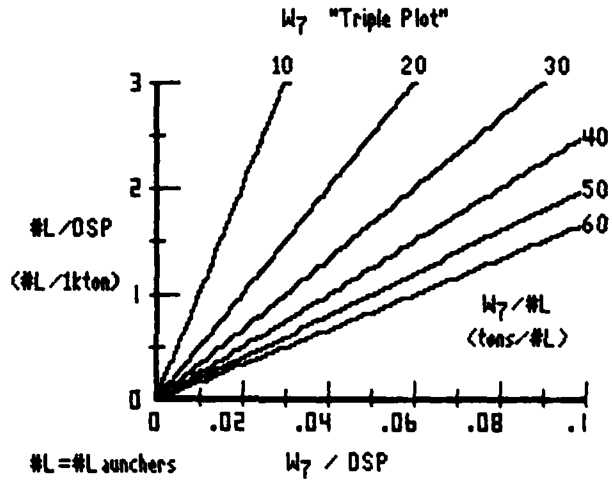


Figure 5.8 Basic "Triple Plot" W_7

implementation are the same as those used for the historical trend data base. It should be noted that the units are, in some cases, of a different magnitude to allow for better scaling and more meaning. This is accounted for by the use of conversion constants in the equations used to create the plots. All "triple plots" are referred to by the respective SWBS group to which they apply. The equations used to create the graphs, using the units as indicated in the data base of appendix E, are as follows:

1. $(W_1/\nabla) = (W_1/\Delta_{f1}) * (\Delta_{f1}/\nabla)$
2. $(W_2/SHP) = (W_2/\Delta_{f1}) * [2240/(SHP/\Delta_{f1})]$
3. $(W_3/KW) = (W_3/\Delta_{f1}) * [2240/(KW/\Delta_{f1})]$
4. $(W_4/\#s) = (W_4/\Delta_{f1}) * [1000/(\#s/\Delta_{f1})]$
5. $(W_5/\nabla) = (W_5/\Delta_{f1}) * (\Delta_{f1}/\nabla)$
6. $(W_6/\nabla) = (W_6/\Delta_{f1}) * (\Delta_{f1}/\nabla)$
7. $(W_7/\#1) = (W_7/\Delta_{f1}) * [1000/(\#1/\Delta_{f1})]$

The values used for the left hand side of the equations, which create the curves, should be the same as those shown in the graphs, figures 5.5 through 5.8.

In all of the triple plots above, the left hand side of the equation is the specific weight or weight allocation per capacity of the particular function under investigation. It provides an indication of the subsystem design practice. The first term on the right hand side is the weight fraction or allocation of weight to the function under investigation. The last term of the equation is the capacity to ship size ratio or the capacity of the function designed into the ship relative to its size. Each of the triple plot drivers are discussed individually in their appropriate screen explanation of appendix F.

Figure 5.9 provides an example of how this analysis can be used. Again, as in section 5.2, the new technology frigate of appendix D is examined in the structural "triple-plot" trend analysis where it obviously stands out from the given historical data base for previous frigates. From equation (1) above, it can be seen that the driving capacity for structures is volume and the new frigate has an average ship density of 18.8 lbs/ft^3. This indicates an average volumetric tightness and weight density of the ships subsystems. The hull structural weight fraction is computed as 23.5%. Using equation (1) above, the hull structure specific weight is therefore 4.43, which is lower than any other frigate in the data base. This is an indication of an extremely efficient structural design which combines with the ship density to cause the low structural weight fraction. This implies that for this specific sized frigate, more weight is available for use by other ships functions.

This type of analysis is extremely useful for rapid determination of what the primary design "drivers" are and how the design relates to existing ships.

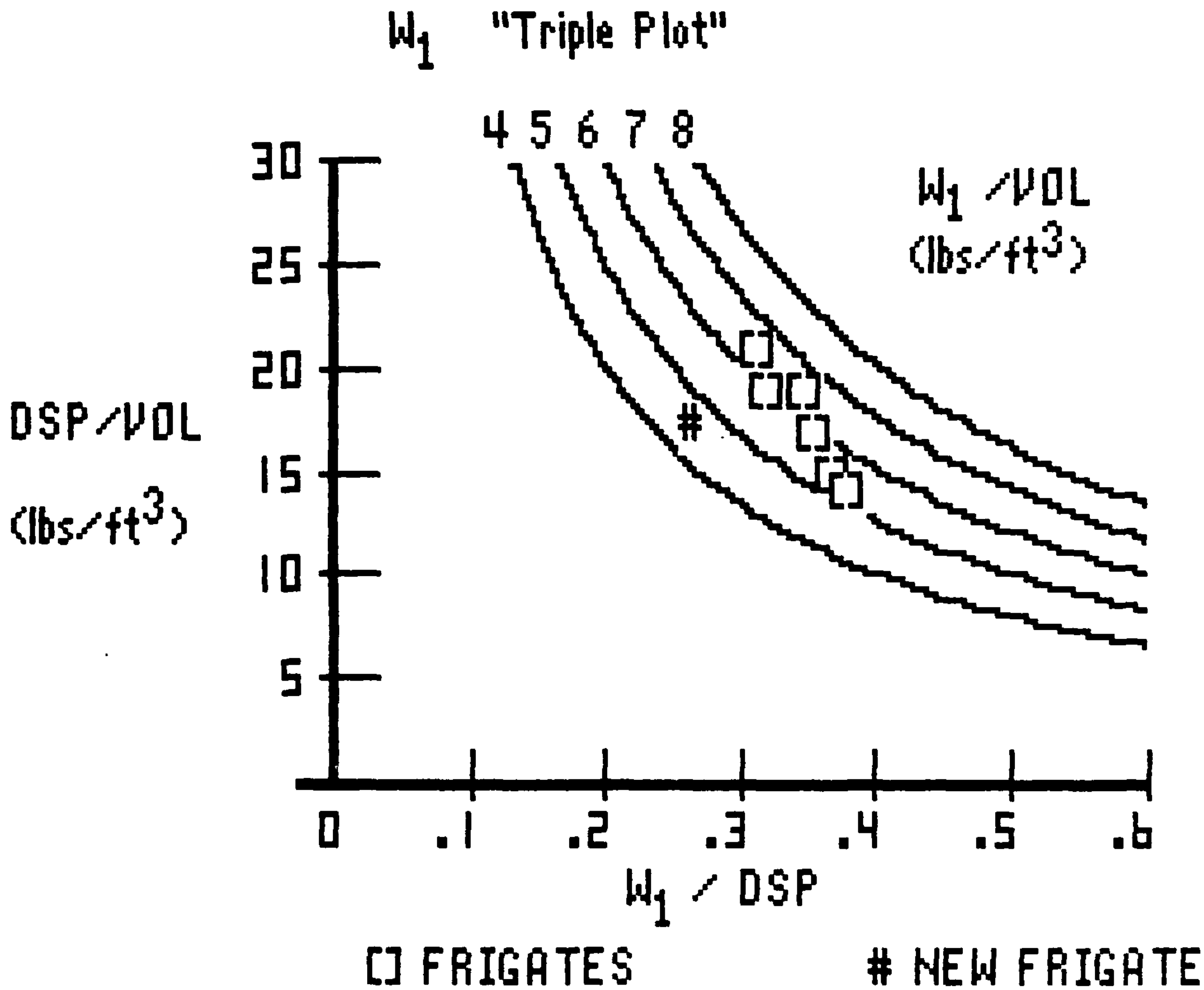


Figure 5.9 Example of New Frigate vs. Standard Frigates "Triple Plot" Structural Trend Analysis

5.4 Programming Notes

Figure 5.10 illustrates the general flow path for the trend analysis section of the program. The menu section will include both the time history and "triple plots" available, of which the user will select only one. He will then be prompted to select the type of ships to which he desires to compare his new design. He may select any combination of, or all of the three available groups; frigates, destroyers, cruisers. After this selection, the user will be provided with a complete listing of all ships in the data base to allow him to select the design he wishes to do the trend analysis on. The plot is then displayed, after which the user may depress a "control key" which will open a window on the screen and prompt him to select either:

- select new ship from data base
- select new type of ships for trend comparison
- select new trend plot
- print screen
- return to main menu (select analysis type)

The program will then branch accordingly.

The selected data base of existing ships provided in appendix E should be incorporated directly into the main data base in use with the appropriate parameters being called up automatically as a specific screen is requested. The importance of providing different, unique symbols for each type of ship and the new design is again emphasized. Another recommendation that would be beneficial, but not necessary, is the ability to be able to see directly what actual ship each symbol represents. This, however, could result in an extremely cluttered screen if a large existing data base were used. The exact method of internal storage of variables and the drawing and computing of the trend plot graphs is left to the programmer.

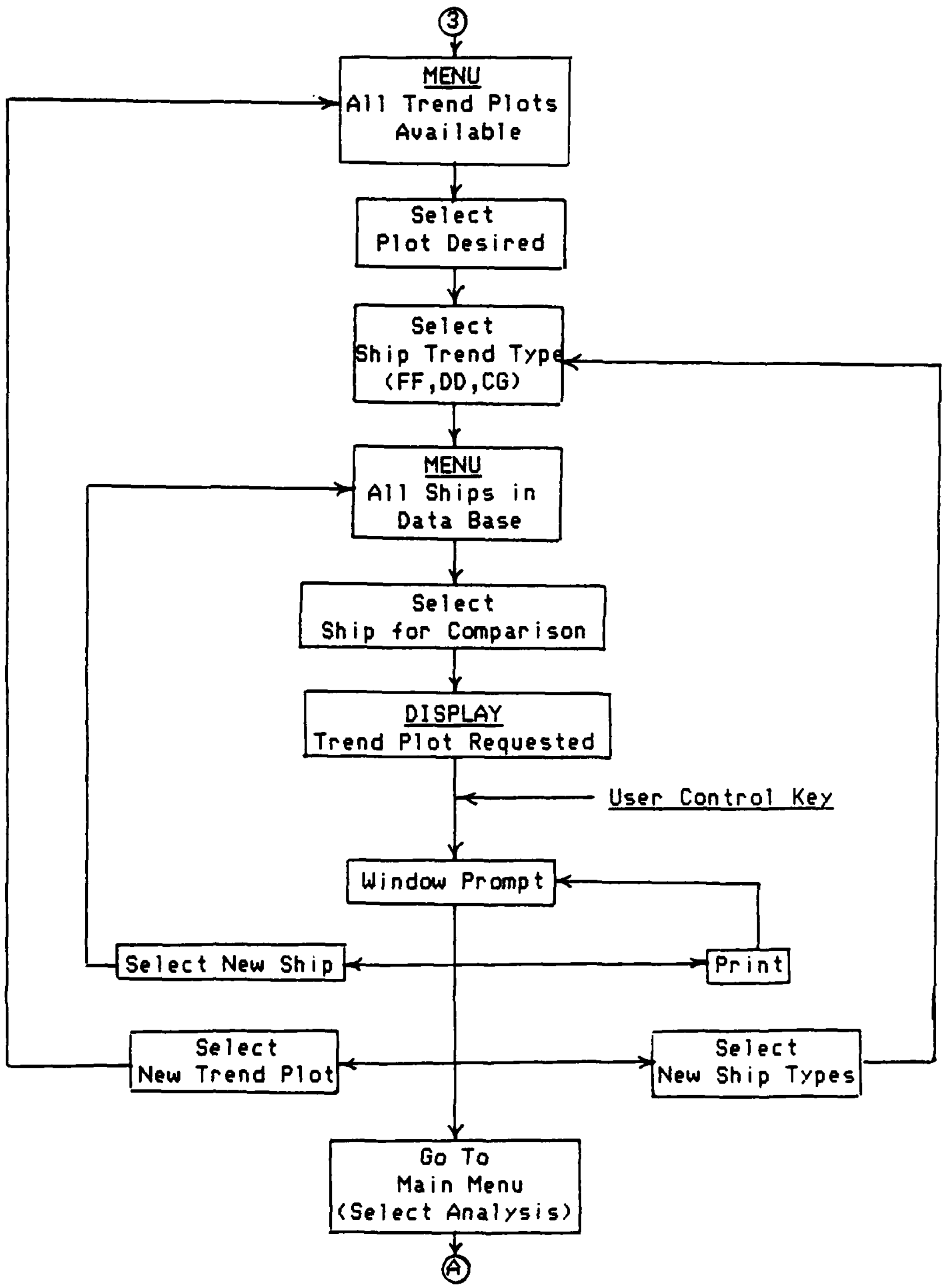


Figure 5.10 Trend Comparative Analysis Flow Chart

CHAPTER 6

INTERFACE TO AN INTEGRATED DATA BASE

6.1 Discussion

Using the methodology proposed in this thesis requires an extensive list of parameters to define the ship or ships under investigation. It is therefore extremely important that these be stored in a central electronic storage facility, more commonly referred to as a data base. When this data base has the ability to use internal relationships between parameters, it becomes an integrated data base. All further discussions will relate to integrated data bases only. Once the data base has been defined, the number of ships and data that can be stored is almost unlimited. As new designs or variants are created, they may be stored for later recall or comparison. Different data bases may be created for conceptual designs, for working designs, and for existing ships. Provided they all use the same structure, or schema, a single application program could be written to access any of the data bases individually allowing selection of any design for comparison.

Two efforts are presently underway at the Naval Sea Systems Command to establish integrated data bases for ship design. The larger effort involves an integrated data base (IDB) for the later stages of design that will serve as a detailed analysis of ships that are in the preliminary to contract design stages. The second effort is referred to as an "Early Stage Integrated Data Base", which is considerably smaller and is being developed at the David Taylor Model Basin for use in feasibility studies. The model developed in this thesis could be used with either IDB or a seperate data base could be developed to store only the required information suggested.

The data base management system selected by the Naval Sea Systems Command is BCS RIM, a Relational Information Management System developed by the Boeing Company. It is powerful, easy to learn, user-oriented, and can be accessed without any knowledge of the physical structure of the data base. It provides easy access to its files, either directly, through an easy-to-use, English-like command language and menu selection facility, or through an application program interface using FORTRAN-callable subroutines. This allows the user to input new data directly, without any interface at all, while providing the tool to call the data using a FORTRAN program to display it in a desired format.

6.2 Implementation Requirements

The initial requirement for implementation of this comparative ship design model for direct use with a data base, is the data base selection. If a new data base is constructed for the sole purpose of supporting this model, it must be directly accessible and requires an application program interface as discussed above. Appendix B lists all required inputs that must be stored in the data base for later recall by the model. The application program interface, as discussed in earlier sections, is then written in FORTRAN or equivalent programming language to access the data base, retrieve the required information and display the requested screen or data. Existing ships, new designs and variants can be initially added to the data base manually or they may be added with a second data base application interface that creates the design parameters, opens the data base and stores the data under a new design name. This type of application is discussed in section 7.

If an existing data base, such as that under development at the David Taylor Model Basin, is used then the parameters presently stored in the data base should be examined to ensure that all those listed in appendix B are supported. If they are not, the RIM data base management system will allow them to be easily added without disrupting the existing data base structure. The application program is then written in the same manner as discussed in the paragraph above.

Once a single application interface program has been written, it can be easily modified to support any existing data base available. If the data bases are of the same type, i.e. RIM, then the task is even easier. Additionally, if care is taken to use the same naming criteria for the schema relations in different data bases, then the interface may be directly compatible. It is in this manner that several data bases may be individually established for different stages of design and the application program merely

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9.2 Further Development

In addition to the three modules developed in this thesis, an effort should be established to investigate and implement a fourth module to compare the cost effectiveness of alternate ship designs. This module should provide an incentive curve ranking to allow ships of the data base to be ranked against each other with a subjective quantitative analysis. Their ranking could be by the major design areas of Combat System Effectiveness, Mobility, Survivability, and Cost. Each of these areas could be further subdivided into more subjective areas. In this manner, a ship will rank highest in its primary design area, instead of an overall ranking. This type of analysis would provide for an even more rapid comparison of variant designs to eliminate those that do not meet the requirements, thus concentrating the detailed analysis on only the best designs.

The comparative analysis methodology developed in this thesis concentrated solely on combatant type ships. Since many of the indices are compatible to other types of ships, it is recommended that modifications be implemented, as necessary, to make the methodology compatible to submarines, auxiliaries, amphibious ships, aircraft carriers and advanced marine vehicles, as the data bases are developed for them.

CHAPTER 9

RECOMMENDATIONS

9.1 Implementation

Since the recommended implementation of the actual computer program is similar for use with both an integrated data base and the ASSET program, it is recommended that a version be developed that will support both systems. This could be performed concurrently with the development of the early stage IDB under development at the David Taylor Model Basin. In this manner, the comparative naval ship design module could be used by both ASSET users and non-users, and would be available to compare ASSET ships to non-ASSET ships.

An additional recommendation involves the initial implementation of the two-ship analysis module on a spreadsheet in the Naval Construction and Engineering curriculum at MIT until a full program is developed. This implementation should be similar to that developed by the author in appendices C and D. It has the capability of being used as an immediate educational tool in naval ship design courses. The recommended system to be used is LOTUS 1-2-3 presently available in the 13A Computer Ship Design Lab on the ZENITH Z-120 personal computer.

of the comparative analysis paths presented in appendix F. This method has been demonstrated in two different studies performed to verify the methodology and convince the reader of the potential use that this type of program may have in the rapid determination of the feasibility of future designs, design changes and new technology assessments.

function to provide the user with a listing of changes relative to the indice he is examining.

Different types of combatants may be compared against each other and all parameters are not required. The methodology is structured to provide the maximum information if all parameters are present, however, the model may be used with less. Those that are not available will merely be listed with a statement of non-applicability. It will be up to the designer to determine if he has sufficient information for the analysis he is performing.

The methodology may be used for all stages of design as well as in an educational environment to demonstrate to a student the overall ship impact of different design practices and standards. The basic methodology developed starts with the assembling of all applicable design data in a data base for future reference. The program then computes the design indices and displays them in three different user requested formats. The user may then either analyse the differences manually or in the case of the two-ship analysis, let the computer assist him with his comparative analysis. In this manner the user may identify differences in the performance requirements as well as design practices and standards thereby determining their impact.

Whereas the fastest and most meaningful method of use would be to implement the methodology in its own computer program, a simple method has been demonstrated to allow the two-ship comparisons to be performed manually on a microcomputer spreadsheet with the aid

CHAPTER 8

CONCLUSIONS

The purpose of this thesis was to develop a methodology that could be implemented on a computer to rapidly and interactively compare new ship designs and technology studies.

Three primary methods of comparison were presented and documented in preparation for implementation as part of a computer program. Applicability was shown for both a straight data base extraction or interfacing to the Navy's Advanced Surface Ship Evaluation Tool (ASSET). The proposed methodology will provide for new designs to be compared to a maximum of six existing data base ships in a bar graph analysis or all preprogrammed ships in a time history or "triple plot" trend analysis. A representative sample of initial data points for the time history and "triple plot" analysis were researched and are provided for the programmer. Additionally, the thesis provides for the detailed analysis of any two ships on a "one on one" basis. The level of detail available includes the ability to examine over 200 selected indices grouped through 31 available screens in 3 levels of analysis. To assist the user in selecting the proper analysis paths to determine reasons for, and impacts of, various differences in the two designs under investigation, the methodology provides for a computer assisted comparative analysis option which will serve as a help

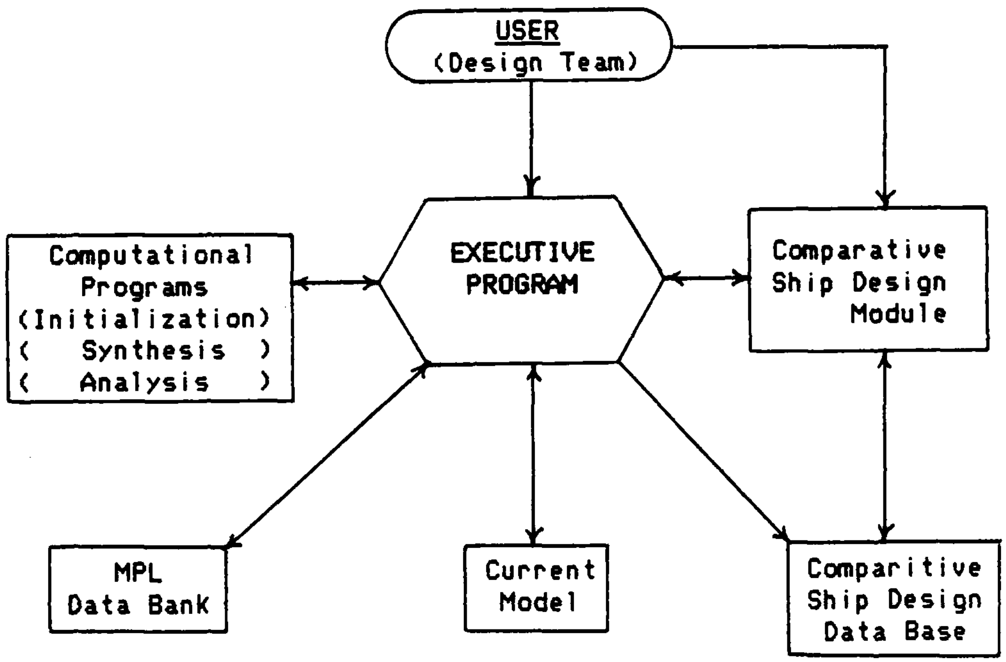

Figure 7.1 Proposed Comparative Ship Design
Module Interface to ASSET

then store the ship in the comparison data base. The user would then modify the ship with some new technology, again as in appendix D with the IRGT propulsion, and then place the variant in the data base. The user may then prompt the ASSET Executive to send him to the Comparative Ship Design Module, where he may assess the overall full ship impact of the new technology as proposed in this thesis. If he sees an error in one of the models, or just wants to make a change, he may return to the ASSET Executive, make all of his changes, "design" and rebalance his ship and then store it back in the data base by overwriting the old file with the new information.

To ensure that the current ship MPL is available for any ASSET ship in the data bank, when a current model is computed and saved to the comparison data base, the current model is simultaneously stored in the MPL under the same name. This will allow the user to recall his ship into ASSET as a current model.

The purpose of ASSET is to provide a total ship evaluation tool for technology evaluation. The addition of the type of comparative analysis module discussed in this thesis would provide the "real-time" comparative analysis necessary to perform this evaluation in relatively short time and on-line without spending a large amount of time analyzing multiple pages of paper output.

module and/or data base could be constructed to allow access from outside the ASSET program which would allow different types of non-ASSET ships to be entered and compared either internally or externally. This type of structure would serve both the ASSET users and non-users.

The ASSET Executive would interact to the comparitive data base in a similar manner as its interaction to the MPL. It should be able to query the ships stored and allow the user full access to all stored information. The Executive would interact with the comparative design module by entering and exiting only. Once the comparative module is called, the user will be in that mode, as described in the previous chapters of the thesis, until he again requests to return to the ASSET Executive, through some type of menu or "control" key. The ASSET Executive also controls the output to the data base from the ASSET Computational Programs. If the user makes the decision to store his ASSET "Current Model" in the comparison data base, he would provide the executive with the appropriate store command, select the name of the ship it is to be stored as, and the executive would then run the appropriate computational programs and output the applicable parameter data to the comparison data base. A warning should be issued any time existing data may be overwritten, such as the case where the user has given a ship name that already exists in the data base.

Using this type of structure would allow the user to enter ASSET, design a baseline ship, as was done in appendix D. He could

ASSET. The actual data used is available as appendix D. When comparing the inputs required for this proposed methodology with the information available and already calculated by ASSET, it is evident that the only immediate shortcomings are in the area of electrical energy allocation, survivability and detailed auxiliaries equipment analysis. The lack of these items did not noticeably impact the overall technology study. Appendix B illustrates directly which required inputs are supported by ASSET and which are not. As demonstrated by the notes of appendix B, some parameters require only slight modification which could be written directly into the new code when the module is incorporated. This thesis will not address the areas not supported by ASSET but makes the recommendation that these areas be implemented in a future version in the manner suggested by this thesis.

In the actual implementation of this methodology as a module for the ASSET program, it is recommended that it be incorporated as a parallel module in the manner described in figure 7.1. This type of implementation would allow the user to move back and forth freely between the ASSET Executive and the Comparitive Ship Design Module. The data base for the comparison module would be seperate from the MPL and information would be stored from ASSET to the comparative data base only on command from the user. The data base would then be similar to those discussed in chapter 6 and the impact on the present ASSET Executive and MPL would be minimized. An additional advantage to this type of structure is that the design ships that the model developed in this thesis will benefit the designer. Presently, a technology tradeoff is performed by establishing a baseline ship on ASSET, then making appropriate changes to reflect the new technology, thus obtaining a variant design. Both the baseline and new technology ships are then individually output to a printer in an extensive data file. Currently the designer then manually compare these two outputs in detail to draw conclusions of the overall impact of the new technology. It is the author's opinion that a great deal of time and effort could be saved if the capability to perform this comparative analysis was available from within the ASSET program. If the results are not as expected, the designer has the immediate option to perform another design iteration without ever leaving the ASSET Executive. Section 7.2 will discuss how the methodology developed in this thesis could be directly coupled to the ASSET program while minimizing the impact on the present ASSET system.

Additional information pertaining to the capabilities and development of the ASSET program is available as an overview in reference (41) with detailed theory available in reference (16).

7.2 Implementation Requirements

An example of the possible interaction of an ASSET technology assessment with this proposed methodology has already been demonstrated in section 3.5.3.1. This example, using a simple spreadsheet type of analysis, used only available output from

CHAPTER 7

INTERFACE TO ASSET

7.1 Discussion

The Advanced Surface Ship Evaluation Tool (ASSET), which has been under development since 1980, is an interactive computer-based total ship technology evaluation tool. It employs computational modules with state-of-the-art engineering capabilities appropriate for feasibility level studies. ASSET has been carefully constructed for compatibility to Naval Sea Systems Command standards, nomenclature, practices and philosophy for early stage ship design. Elements addressed within the program include the areas of geometric definition of the hull and superstructure, hull structures, resistance and propulsion, machinery, weights, hydrostatics, seakeeping, cost and manning. Although its primary module in use at this time is in the area of surface naval combatants, a current model exists for hydrofoils and SWATH's (Small Waterplane Area Twin Hull) and future ship types to be included are naval auxiliaries, aircraft carriers, planing craft and air cushion support craft.

The primary focus of ASSET is to determe the impact of a broad spectrum of technologies on a whole ship system. The method of performing these technology studies is addressed in depth by Goddard in reference (40). It is in this context of comparing impacts of technological advancements on either existing or new needs to ask the user to which data base he desires access to retrieve the ship he wishes to analyse. Since the computer processing time required for the application program to search the data base for the required information to be retrieved is directly proportional to the size of the data base, this method of using several data bases is recommended, however, the final decision should rest with the programmer, who is familiar with the data base in use.

As more ships become available in the data base, the model allows for a greater selection of comparisons and becomes an increasingly powerful tool for comparative ship design analysis.

28. "Electric Plant Margin Policy for Non-Nuclear Surface Ships", Naval Sea Systems Command Memorandum SEA 03/05 ser 173 dated 7 April 1980

29. "Weight and KG Margin Policy for Surface Ships", SHIPSYSENGDESINST. 9096.1, dated 25 September 1978

30. "Power Margin Policies for Surface Ship Design", SHIPSYSENGDESINST. 9020.8, dated 18 October 1974

31. "Area/Volume Data Base; Cruisers, Destroyers, Frigates", Naval Sea Systems Command Publication 3211

32. "DDG51 Pre-Contract Design Weight Estimate", NAVSEA Code 55W2, 19 August 1983

33. "DDG51 Final Contract Design Baseline Area/Volume Report", NAVSEA Code 503, 26 June 1984

34. "DDG51 Contract Design Electric Load Analysis", Gibbs & Cox Inc. Report, 3 August 1983

35. "DDG51 Ship Manpower Document", NAVSEA 55W2 Draft, 10 July 1984

36. "DD963 Class Ship Final Weight Report", Ingalls Shipbuilding Report, 25 November 1975

37. "DD963 C&A Compartment Volume List", Naval Sea Systems Command, 18 February 1976

38. "Summary of Electrical Loads for DD963", Naval Sea Systems Command

39. "DD963 Ship Manpower Document", Naval Sea Systems Command, 17 January 1976

40. Goddard, C.E. "A Methodology for Technology Characterization and Evaluation for Naval Ships", MIT Ocean Engineer Thesis, June 1985

41. Sheridan, D., Clark, D.,Jones, R., and Fein, J., "The ASSET Program - A Current Navy Initiative", SNAME Spring Meeting, Los Angeles, Calif, April 1984

APPENDIX A

SUMMARY OF SCREENS

Summary listing of all two-ship analysis levels, screens, and when used, subcategories of screens.

LEVEL 1: PRIMARY CHARACTERISTICS

Screen 1-1:	Cost and Size Characteristics	tabular
	Total Costs	
	Ship Size	
Screen 1-2:	Shape Characteristics	tabular
Screen 1-3:	Ship Performance	tabular
	Mobility	
	Hull Efficiency	
	Survivability	
Screen 1-4:	HM&E System Selection	tabular
	Main Propulsion	
	Electrical	
	Auxiliary	
	Structure/Materials	
	Deck Heights	
	Manning	
Screen 1-5:	Combat Systems Selection	tabular
	Anti-Air Warfare (AAW)	
	Anti-Submarine Warfare (ASW)	
	Surface/Strike Warfare (SUW)	

LEVEL 2: RESOURCE ALLOCATION

Screen 2-1:	SWBS Weight Fractions	graphical
Screen 2-2:	Load Weight Fractions	graphical
Screen 2-3:	Functional Weight Allocation	graphical

Screen 2-4: SSCS Volume Fractions graphical

Screen 2-5: Space Type/Location Volume graphical

Screen 2-6: Functional Volume Allocation graphical

Screen 2-7: Electrical Energy Allocation graphical

Screen 2-8: Functional Energy Allocation graphical

Installed HP

Fuel Usage

Electrical

Screen 2-9: Manning Allocation Fraction graphical

Screen 2-10: Functional Manning Allocation graphical

Screen 2-11: Basic Construction Cost Allocation tabular

Screen 2-12: Functional Allocation Cost graphical

Screen 2-13: Cost Fractions graphical

LEVEL 3: FUNCTIONAL INVESTIGATION

Screen 3-1: Containment Weight Breakdown graphical

Structure Weight

Outfit and Furnishings Weight

Screen 3-2: Containment Indices tabular

Containment drivers

Related Containment ratios

Screen 3-3: Main Propulsion Breakdown graphical

Weight

Volume

Screen 3-4:	Main Propulsion Indices	tabular
	Main propulsion drivers	
	Related Main Propulsion ratios	
Screen 3-5:	Electrical Plant Breakdown	graphical
	Weight	
	Volume	
Screen 3-6:	Electrical Indices	tabular
	Electrical drivers	
	Related Electrical ratios	
Screen 3-7:	Auxiliary Breakdown	graphical
	Weight	
	Volume	
Screen 3-8:	Auxiliary Indices	tabular
	Auxiliary drivers	
	Related Auxiliary ratios	
Screen 3-9:	Combat Systems Breakdown	tabular
	Combat Systems Weight	
	Command & Surveillance Weight	
	Armament Weight	
	Combat Systems Volume	
	Command and Surveillance Volume	
	Armament Volume	
Screen 3-10:	Combat Systems Indices	tabular
	Combat Systems Drivers	
	Related Combat Systems ratios	

Screen 3-11: Human Support Breakdown	graphical
Weight	
Volume	
Screen 3-12: Human Support Indices	tabular
Human Support Drivers	
Related Human Support ratios	
Screen 3-13: Margin Summary	graphical

APPENDIX B

SUMMARY OF REQUIRED INPUT PARAMETERS

WITH ASSET RELATIONSHIP

All required input parameters for the methodology are summarized by major category and related to their support or non-support by the Advanced Surface Ship Evaluation Tool (ASSET). If the ASSET support is present with only minor modifications, then the modifications required are indexed by number and explained at the end of the appendix. If they are supported by ASSET then it is noted whether it is by calculation to the output file or within the Main Program Library (MPL), or both.

To use all indices in the two-ship analysis, all of the listed parameters are required in the data base for each ship analysed.

PARAMETERS REQUIRED:		SUPPORTED BY ASSET: CALC	MPL
PRIMARY CHARACTERISTICS:			
DSP.FL	Full Load Displacement	X	X
DSP.LS	Light Ship Displacement	X	
VOL	Total Volume	X	X
L.BP	Length Between Perpendiculars	X	
L.OA	Length Overall		
B.WL	Beam at Waterline	X	
B.MAX	Beam maximum at Deck Edge		
D	Depth at Midships	X	
T	Draft (maximum)	X	
C.P	Prismatic Coefficient	X	X
C.X	Maximum Section Coefficient	X	X
C.W	Waterplane Coefficient	(1)	
WEIGHTS:			
W.1	HULL STRUCTURE	X	X
W.11	Shell and Supporting Structure	X	
W.12+13+14	Structure Bulkheads/Decks	X	
W.15	Deck House Structure	X	
W.16+17+19	Other Structures	X	
W.18	Foundations	X	
W.2	PROPULSION PLANT, GENERAL	X	X
W.23	Propulsion Units	X	
W.24	Transmission and Propulsor Sys	X	
W.25+26+29	Propulsion Support Sys	X	
W.21+22	Other Propulsion		
W.3	ELECTRIC PLANT, GENERAL	X	X
W.31	Electric Power Generation	X	
W.32	Power Distribution Sys	X	
W.33	Lighting System	X	
W.34+39	Electric Support Sys	X	
W.4	COMMAND AND SURVEILLANCE	X	X
W.43+44	Interior/Exterior Comms	X	
W.45	Surveillance Sys (Surface)	X	
W.46	Surveillance Sys (Underwater)	X	
W.41+42+47+ 48+49	Other Command & Surv	X	
W.5	AUXILIARY SYSTEMS	X	X
W.51	Climate Control	X	
W.52+53	Seawater/Freshwater Sys	X	
W.56	Ship Control Systems	X	
W.57+58	Replenishment/Mech Hdling Sys	X	
W.54+55+59	Fluid/Misc Support Sys	X	

W.6	OUTFIT AND FURNISHINGS	X	X
W.61+62+63+69	Non-Crew Related	X	
W.64+65+66+67	Crew Related	X	
W.7	ARMAMENT	X	X
W.71	Guns and Ammunition	X	
W.72	Missiles and Rockets	X	
W.73 thru 79	Other Armament	X	
W.m	D&C Margin Wt	X	
W.al	Architectural Limit Wt		
F1	Crew and Effects	X	
F2	Ordnance	X	
F23+F26	Aviation Related Support	X	
F4	Fuels and Lubricants	X	
F52	Freshwater	X	
F3+F5+F6	Other Loads	X	

<u>KG:</u>

KG.ls	Light Ship KG	
KG.fl	Full Load KG	X
KG.m	KG Acquisition Margin	
KG.al	Architectural Limit KG	

<u>VOLUMES:</u>

V.hull	Hull Volume	X
V.dkhs	Deckhouse Volume	X
V1.	MISSION SUPPORT	X
V1.1	Command, Communications, Surv.	X
V1.11	Exterior Communications	X
V1.121	Surface Surveillance	X
V1.122	Underwater Surveillance	X
V1.15	Interior Communications	X
V1.13+1.14+1.16	Other C&S Volume	X
V1.2	Weapons	X
V1.21	Guns	X
V1.22	Missiles	X
V1.23	Rockets	X
V1.24+1.25+ 1.26+1.27	Other Armament Vol	X
V1.3	Aviation	X
V1.34	Aircraft Stowage	X
V2	HUMAN SUPPORT	(2)
V2.1	Living	X
V2.2	Commissary	X
V2.3 thru V2.7	Other Spaces and Stowage	X
V3	SHIP SUPPORT	(3)
V3.5	Deck Systems	(4)
V3.9	Tanks/Voids	(5)

V4	SHIP MOBILITY	(6)	
V4.1	Propulsion Systems	X	
V4.15	Electric		
V4.2	Propulsor and Transmission Sys		
V4.3	Auxiliary Machinery	(7)	
V4.33	Electrical	(8)	
V5	UNASSIGNED	X	

AREAS:

A2.	HUMAN SUPPORT AREA	(9)	
A2.11+2.211	Officer Living/Messing	X	
A2.12+2.212	CPO Living/Messing	X	
A2.13+2.213	Crew Living/Messing	X	

ENERGY:

Note: Four possible combinations
10 degree day / 90 degree day
Battle / Cruise

E.i	Installed KW	X	
E.t	Maximum KW	(10)	
E.2	Propulsion Related KW		
E.3	Electrical Related KW		
E.4	Command and Control KW		
E.5	Auxiliary Related KW		
E.6	Outfit and Furnishings KW		
E.7	Armament KW		
E.am	Acquisition Margin KW	(11)	
E.slm	Service Life Margin KW	(11)	

MANNING:

M.a	Total Accomodations	X	
M.aoff	Officer Accomodations		X
M.acpo	CPO Accomodations		X
M.aenl	Enlisted Accomodations		X
M.t	Total Complement	(12)	
M.off	Officer Complement	X	
M.cpo	CPO Complement	X	
M.enl	Enlisted Complement	X	
M.m	Manning Margin		
M.cs	Combat Systems Dept. Manning	X	
M.ops	Operations Dept. Manning	X	
M.eng	Engineering Dept. Manning	X	
M.na	Nav/Admin Dept. Manning	X	
M.sup	Supply Dept. Manning	X	
M.av	Aviation Dept. Manning	X	

COST:

Note: Lead Ship or Follow Ship

C.1	Structural Related Cost	X
C.2	Propulsion Related Cost	X
C.3	Electrical Related Cost	X
C.4	Command and Surveillance Cost	X
C.5	Auxiliary Related Cost	X
C.6	Outfit and Furnishings Cost	X
C.7	Armament Related Cost	X
C.m	Design/Const. Cost Margin	X
C.de	Design/Engr. Costs (Gp 8)	X
C.con	Const. Services (Assy-Gp 9)	X
C.pr	Profit	X
C.csgfe	Combat System GFE Costs	(13)
C.oth	Total Other Costs	(14)
C.HM&E	HM&E GFE	(15)
C.pmg	Proj Mgr Growth	(16)
C.ls	Total Cost-Lead Ship	(17)
C.bcfs	Basic Constr. Cost-Follow Ship	(18)
C.fs	Total Cost-Follow Ship	(17)

SHIP PERFORMANCE:

Mobility:		
Max Sustained Speed (80% power)	X	
Max Trial Speed (100% power)	X	
Range at Endurance Speed	X	
Endurance Period due to fuel @ endurance speed	(19)	
Endurance due to Stores		X
Endurance due to Chilled Stores		X
Endurance due to Frozen Stores		X
Shaft Horsepower Available	X	
Shaft Horsepower Required @ Endurance Speed	X	
Shaft Horsepower Required @ Sustained Speed	X	
Hull Efficiency:		
Drag (Sustained Spd)	X	X
Drag (Endurance Spd)	X	X
Bales Rank	X	
Survivability:		
Blast		
Fragmentation		
Shock		
NBC		
Noise Signature		
IR Signature		
Radar Signature		

HM&E SYSTEM SELECTION:

Main Propulsion:		
Total Boost Power Avail/Reqd @ Sust Spd/Growth Pot	XXX	
Boost Engine Type/Number/Rating	XXX	XXX
Cruise Engine Type/Number/Rating	XXX	XXXX
Transmission System Type	X	X
Propeller Type/Number/RPM	XXX	XXX
Propeller Open Water Efficiency (sustained)	X	
Propeller Open Water Efficiency (endurance)	X	
Propulsion Coefficient	X	
Specific Fuel Consumption Rate @ Endurance	X	
Specific Fuel Consumption Rate @ Sustained	X	
Electric Power:		
Total 60Hz KW Avail/Maximum Load/Growth Pot.	XXX	X
Total 400Hz KW Avaail/Max Load/Growth Pot.		
60 Hz Generator Type/No./Rating	XXX	XXX
400 Hz Converter Type/No./Rating		
Specific Fuel Consumption Rate (SFCA)	X	
Auxiliary:		
Total AC Avail/MaxLoad/Growth Pot.		
AC Type/No./Rating		
Heating Type/Rating		
Firepump Type/No./Rating		
Seawater Type/No./Rating		
HP Air Compressor Type/No./Rating		
LP Air Compressor Type/No./Rating		
Distilling Plant Type/No./Rating		
Boats Type/No.		
Steering Units T; pe/No.		
Anchors Type/No./Length of Chain		X
UNREP Capability		X
Structure/Materials:		
Hull Materials (array)	X	X
Deckhouse Materials (array)	X	X
Hull Frame Type/Spacing	XX	
Deckhouse Frame Type/Spacing		
Deck Heights:		
Number of Internal Decks in Hull	X	
Number of Internal Decks in Deckhouse	X	
Internal Deck Heights (array)	X	
Hull Average Deck Heights	X	X
Manning:		
Total Accomodations/Total Complement/Growth Pot	XX	
Total Complement (OFF/CPO/ENL)	XXX	
Habitability Classification		X
Flag Configured		X

COMBAT SYSTEM SELECTION: (20)

Anti-Air Warfare (AAW):
Armament (array)
Sensors (array)
Aviation Capabilities (array)
Anti-Submarine Warfare (ASW):
Armament (array)
Sensors (array)
Aviation Capabilities (array)
Surface/Strike Warfare (SUW):
Armament (array)
Sensors (array)
Aviation Capabilities (array)
Command, Control, Communications & Intelligence
Communications
Electronic Warfare
Control

MISCELLANEOUS INPUTS:

HP.shpi	Total installed SHP	X	
HP.geni	Total installed Generator HP		
HP.shpe	Prop HP @ endurance spd	X	
HP.gene	Gen HP @ avg 24 hr load	X	
SFC.e	Prop SFC @ endurance spd	X	
SFCA.e	Gen SFC @ avg 24 hr load	X	
E.24	Average 24 hr Elec Load	X	X
# lchr	Number of Launchers	(21)	
# snsr	Number of Sensors	(21)	
YEAR	Year Commissioned (IOC)		X

NOTES: Equivalent ASSET parameters

(1) Use (Waterplane Area)/(L.bp * B.wl)

NOTE: For volumes where only area is given, multiply area by average deck height to get volume.

(2) V2.0-V2.8-V2.9
(3) V3.0-V3.41-V3.51+V2.8+V2.9+V4.3
(4) V3.42
(5) V3.9+V2.8+V2.9+V4.3
(6) V4.0+V3.41+V3.51-V4.3
(7) V3.41
(8) V3.51

(9) A2.0-A2.9-A2.8

(10) Use Peak Electric Load
(11) Use (.40 * Elect Margin KW for Acquisition Margin)

(12) Use Required Manning Column

(13) Payload Cost
(14) Outfitting+Post Delivery+NAVSEA Support +
     + Change Orders + [.6 * (HM&E+Growth)]
(15) .4 * (HM&E + Growth)
(16) .6 * (HM&E + Growth)
(17) Ship Plus Payload Cost
(18) PRICE (follow ship)

(19) [usable Fuel Wt/(1ton/hr)]/(24 hrs/day) : Mach Module Menu 4

(20) List of Combat Systems is available in ASSET, however, a new array must be established to allow user to specify which warfare area and sub-area each system will be a part of. The module will then know where to put each system.

(21) Add array to allow user to mark which systems are to be counted as either sensors or launchers.

V4.2/SHP	Trans/Prop Spec Vol	-85.0%
E.2/W.2	Prop KW/Weight Ratio	24.0%
C.2/W.2	Prop Cost/Weight Ratio	23.6%

SCREEN 3-5: ELECTRICAL PLANT BREAKDOWN

WEIGHT:		
W.31/W.3	Power Generation Wt	-4.8%
W.32/W.3	Power Distribution Wt	58.4%
W.33/W.3	Lighting Wt	2.4%
W.34+39/W.3	Support Systems Wt	629.4%
VOLUME:		
V4.15/V.e	Machinery Box Elec Vol	-100.0%
V4.33/V.e	Aux Space Elec Vol	-33.2%

SCREEN 3-6: ELECTRICAL INDICES

ELECTRICAL DRIVERS:		
W.3/DSP.FL	Electrical Wt Fraction	36.6%
W.3/E.i	Electrical Spec Wt	9.3%
E.i/DSP.FL	Elec Capac Ship Size Ra	15.9%
RELATED ELECTRICAL RATIOS:		
W.3/V.e	Electrical Density	124.5%
V.e/VOL	Electrical Vol Fraction	-39.1%
W.31/E.i	Power Gen Specific Wt	-23.9%
V.e/E.i	Electrical Spec Vol	-51.3%
E.3/W.3	Elec KW/Weight Ratio	38.9%
C.3/W.3	Elec Cost/Weight Ratio	-33.4%

SCREEN 3-7: AUXILIARY BREAKDOWN

WEIGHT:		
W.51/W.5	Climate Control Wt	-4.7%
W.52+53/W.5	Seawater/Freshwater Wt	24.2%
W.54+55+59/W.5	Fluid Systems Wt	18.3%
W.56/W.5	Ship Control Wt	-11.7%
W.57+58/W.5	Replenish/Mech Hndlg Wt	4.4%
VOLUME:		
V3.5/V.ax	Deck Systems Volume	-51.8%
V4.3-4.33/V.ax	Auxiliary Mach Volume	54.4%

SCREEN 3-8: AUXILIARY INDICES

AUXILIARY DRIVERS:		
W.5/DSP.FL	Auxiliary Wt Fraction	8.5%
W.5/VOL	Auxiliary Spec Wt	16.0%
VOL/DSP.FL	Ship Specific Vol	-13.3%
RELATED AUXILIARY RATIOS:		
W.5/V.ax	Auxiliary Density	-17.4%
V.ax/VOL	Auxiliary Volume Frac	31.4%
E.5/W.5	Auxiliary KW/Wt Ratio	15.4%
C.5/W.5	Auxiliary Cost/Wt Ratio	39.3%

W.16+17+19/W.1	Other Structural	1.4%
OUTFIT AND FURNISHINGS:		
W.64+65+66+ 67/W.6	Crew Related	51.8%
W.61+62+63+ 69/W.6	Non-crew Related	10.9%

SCREEN 3-2: CONTAINMENT INDICES

CONTAINMENT DRIVERS:		
W.1/DSP.FL	Structural Wt Fraction	-4.8%
W.6/DSP.FL	Outfit & Furn. Wt. Frac	22.3%
W.1/VOL	Hull Struc Specific Wt	1.7%
W.6/VOL	Outfit & Furn. Spec Wt	30.7%
VOL/DSP.FL	Ship Specific Volume	-13.3%
RELATED CONTAINMENT RATIOS:		
W.cf/V.c	Containment Density	12.3%
W.11+12+13+ 14/V.Hull	Basic Hull Struc Density	-13.1%
W.15/V.dh	Deckhouse Struc Density	91.8%
W.18/W.2+3+ 4+5+7	Foundations Wt Fraction	14.3%
C.c/W.cf	Containment Cost/Wt rat.	-15.5%

SCREEN 3-3: MAIN PROPULSION BREAKDOWN

WEIGHT:		
W.23/W.2	Propulsion Units Wt	-9.3%
W.24/W.2	Transmission/Prop Wt	11.2%
W.25+26+29/W.2	Propulsion Support Wt	-24.0%
W.21+22/W.2	Other Propulsion Wt	0.0%
VOLUME:		
V4.1-4.15/V.pt	Propulsion Sys Volume	-1.5%
V4.2/V.pt	Transmission/Prop Vol	-81.3%

SCREEN 3-4: MAIN PROPULSION INDICES

MAIN PROPULSION DRIVERS:		
W.2/DSP.FL	Main Propulsion Wt Frac	-4.9%
W.2/SHP	Main Propulsion Spec Wt	-23.9%
SHP/DSP.FL	Main Prop Ship Size Rat	15.9%
R.Te/DSP.FL	Drag/Disp Ratio (endur)	-16.1%
R.Ts/DSP.FL	Drag/Disp Ratio (sust)	24.6%
PC	Propulsion Coefficient	11.9%
RELATED MAIN PROPULSION INDICES:		
W.2/V.pt	Main Propulsion Density	-8.3%
V.pt/VOL	Main Prop Volume Frac	-6.1%
W.23/SHP	Prop Units Specific Wt	-27.4%
W.24/SHP	Trans/Prop Specific Wt	-11.0%
W.25+26+29/SHP	Support/Fluids Spec Wt	-39.2%
V.pt/SHP	Prop & Trans Spec Vol	-24.9%
V4.1-4.15/SHP	Prop Systems Spec Vol	-21.2%

SCREEN 2-9: MANNING ALLOCATION

M.off/M.a	Officer Ratio	0.0%
M.cpo/M.a	CPO Ratio	5.0%
M.enl/M.a	Crew Ratio	14.7%
M.m/M.a	Manning Margin	15.4%

SCREEN 2-10: FUNCTIONAL MANNING ALLOCATION

M.cs/M.a	Combat Systems Manning	18.7%
M.ops/M.a	Operations Manning	15.1%
M.eng/M.a	Engineering Manning	15.4%
M.na/M.a	Nav/Admin Manning	5.9%
M.sup/M.a	Supply Manning	22.9%
M.av/M.a	Aviation Manning	-100.0%

SCREEN 2-11: BASIC CONSTRUCTION COST ALLOCATION

Note: Lead Ship Costs

C1/C.bc	Hull Structure	-38.1%
C2/C.bc	Propulsion Plant	17.5%
C3/C.bc	Electric Plant	-39.6%
C4/C.bc	Command and Surveillance	3.2%
C5/C.bc	Auxiliary	5.9%
C6/C.bc	Outfit and Furnishings	29.3%
C7/C.bc	Armament	88.3%
C.m/C.bc	D+C Margin	NA
C.de/C.bc	Design/Engr (Gp 8)	2.1%
C.con/C.bc	Constr. Svcs/Assy (Gp9)	1.6%
C.pr/C.bc	Profit	2.0%
C.HM&E/C.BC	HM&E GFE	2.0%

SCREEN 2-12: FUNCTIONAL COST ALLOCATION

Note: Lead Ship Costs

C.cs/C.t	Combat Systems	27.5%
C.ma/C.t	Machinery	5.1%
C.c/C.t	Containment	-11.5%

SCREEN 2-13: COST FRACTIONS

C.csgfe/C.ls	Combat Sys GFE/Lead Ship	33.4%
C.csgfe/C.fs	Combat Sys GFE/Follow	33.4%
C.bcls/C.ls	Basic Constr/Lead Ship	2.0%
C.bcfs/C.fs	Basic Constr/Follow	1.9%
C.fs/DSP.fl	Follow Ship Cost/Weight	5.3%
C.fs/VOL	Follow Ship Cost/Volume	21.4%

SCREEN 3-1: CONTAINMENT WT BREAKDOWN

STRUCTURE WEIGHT:

W.11/W.1	Shell and Supports	-19.3%
W.12+13+14/W.1	Hull Struc Blkhds/Decks	-5.4%
W.15/W.1	Deckhouse	35.9%
W.18/W.1	Foundations	14.3%

SCREEN 2-5: SPACE TYPE/LOCATION VOLUME

V.hull/VOL	Hull Volume			1.2%
V.dh/VOL	Deckhouse Volume			-29.1%
V.tk/VOL	Tankage/Void Volume			-23.8%
V.lo/VOL	Large Space Volume			-6.3%
V.a/VOL	Arrangeable Volume			-3.7%

SCREEN 2-6: FUNCTIONAL VOLUME ALLOCATION

V.cs/VOL	Combat Sys Volume			-6.0%
V.ma/VOL	Machinery Related Vol			-4.9%
V.c/VOL	Containment Volume			-5.3%
V.5/VOL	Unassigned Volume			-90.3%

SCREEN 2-7: ELECTRICAL ENERGY ALLOCATION

Note: max load/ 10 deg day/Battle

E2/E	Propulsion Plant			17.9%
E3/E	Electric Plant			26.0%
E4/E	Command and Surveillance			92.0%
E5/E	Auxiliary			-12.3%
E6/E	Outfit & Furnishings			136.4%
E7/E	Armament			-29.8%
Em/E	Margin (Acq.+Serv Life)	NA	NA	

Note: installed load/10 deg/Battle

E2/E	Propulsion Plant			17.9%
E3/E	Electric Plant			26.0%
E4/E	Command and Surveillance			92.0%
E5/E	Auxiliary			-12.3%
E6/E	Outfit & Furnishings			136.4%
E7/E	Armament			-29.8%
Em/E	Margin (Acq + Serv Life)			73.6%

SCREEN 2-8: FUNCTIONAL ENERGY ALLOCATION

INSTALLED HP:

HP.shpi/HP.t	Propulsion HP Allocation	25.0%
HP.geni/HP.t	Electrical HP Allocation	63.7%

FUEL USAGE:

FF.mp/FF.t	Propulsion Fuel Alloc.	20.5%
FF.gen/FF.t	Electrical Fuel Alloc.	40.2%

ELECTRICAL:

Note: max load/10deg day/Battle

E.cs/E.t	Combat System Elec	47.8%
E.ma/E.t	Machinery Elec	-.1%
E.c/E.t	Containment Elec	136.4%

Note: instal load/10deg day/Battle

E.cs/E.i	Combat System Elec	65.5%
E.ma/E.i	Machinery Elec	11.9%
E.c/E.i	Containment Elec	164.7%

Control

SCREEN 2-1: SWBS WEIGHT FRACTIONS

LIGHT SHIP:		
W.1/DSP.LS	Structural	-4.84%
W.2/DSP.LS	Main Propulsion	-4.9%
W.3/DSP.LS	Electrical	36.6%
W.4/DSP.LS	Command & Surveillance	7.0%
W.5/DSP.LS	Auxiliary	8.5%
W.6/DSP.LS	Outfit & Furnishings	22.3%
W.7/DSP.LS	Armament	94.1%
W.m/DSP.LS	Margin	7.8%
FULL LOAD:		
W.1/DSP.FL	Structural	-4.84%
W.2/DSP.FL	Main Propulsion	-4.9%
W.3/DSP.FL	Electrical	36.6%
W.4/DSP.FL	Command & Surveillance	7.0%
W.5/DSP.FL	Auxiliary	8.5%
W.6/DSP.FL	Outfit & Furnishings	22.3%
W.7/DSP.FL	Armament	94.1%
W.m/DSP.FL	Margin	6.1%

SCREEN 2-2: LOAD WEIGHT FRACTIONS

W.fuel/W.ld	Liquid (fuel & Lube)	-13.0%
W.ce/W.ld	Crew and Effects	15.2%
W.ord/W.ld	Ordnance	149.1%
W.av/W.ld	Aviation	-100.0%
W.oth/W.ld	Others	-8.9%
W.ld/DSP.FL	Load to Full Load ratio	-6.2%
DSP.ls/DSP.fl	Lightship to Full ratio	12.6%

SCREEN 2-3: FUNCTIONAL WT. ALLOCATION

W.csl/DSP.LS	LS Combat Sys Weight	44.7%
W.mal/DSP.LS	LS Machinery Weight	16.4%
W.cl/DSP.LS	LS Containment Weight	7.0%
W.csf/DSP.FL	FL Combat Sys Weight	56.5%
W.maf/DSP.FL	FL Machinery Weight	2.1%
W.cf/DSP.FL	FL Containment Weight	6.3%

SCREEN 2-4: SSCS VOLUME FRACTIONS

V1/VOL	Mission Support	-6.0%
V2/VOL	Human Support	-6.5%
V3/VOL	Ship Support	-13.1%
V4/VOL	Ship Mobility	5.1%
V5/VOL	Unassigned	-90.3%

Deckhouse Frame Type/Spacing	*
Other	
DECK HEIGHTS:	
Number internal decks in hull	
Number internal decks in deckhouse	
Internal Deck Heights (array above BL)	*
	*
	*
	*
Hull Avg Deck Height	*
Other	
MANNING:	
Total Accom/Complement/Growth Pot.	*
Total Complement (OFF/CPO/ENL)	*
Habitability Classification	*
Flag Configured	
Other	

SCREEN 1-5: COMBAT SYSTEMS SELECTION

ANTI-AIR WARFARE:	
Armament	*
	*
	*
Sensors	*
	*
	*
Aviation Capabilities	*
ANTI-SUBMARINE WARFARE:	
Armament	
Sensors	*
	*
Aviation Capabilities	*
SURFACE/STRIKE WARFARE:	
Armament	*
	*
Sensors	*
	*
Aviation Capabilities	*
COMMAND/CONTROL/COMM/INTEL:	
Communications	
Electronic Warfare	

Propeller Type	
Propeller Number/RPM	*
Propeller Open Wtr Effy (sustained)	2.8%
Propeller Open Wtr Effy (endurance)	4.3%
Propulsion Coefficient (PC)	11.9%
SFC @ Endurance Spd	*
SFC @ Sustained Spd	*
Other	
ELECTRIC POWER:	
Total 60 Hz Available	25.0%
Total 60 Hz Max Load	31.9%
60 Hz Growth Potential (all Gen)	18.9%
Total 400 Hz Available	20.0%
Total 400 Hz Max Load	33.3%
400 Hz Growth Potential	12.3%
60 Hz Generator Type	
60 Hz Generator Number/Rating	*
400 Hz Converter Type	*
400 Hz Converter Number/Rating	*
SFCA	*
Other	
AUXILIARY:	
Total AC Available	20.0%
AC Maximum Load	33.3%
AC Growth Potential	33.3%
AC Type	
AC Number/Rating	*
Heating Type	*
Heating Rating	*
Firepump Type	
Firepump No./Rating	
Seawater Pump Type	
Seawater Pump No./Rating	*
HP Air Compressor Type	
HP Air Compressor No./Rating	
LP Air Compressor Type	*
LP Air Compressor No./Rating	*
Distilling Plant Type	*
Distilling Plant No./Rating	*
Boats Type/No.	*
Steering Units Type/No.	
Anchors Type/No.	
Anchors Length of Chain	
UNREP Capability	
Other	
STRUCTURE/MATERIALS:	
Hull Materials (array)	
Deckhouse Materials (array)	*
Hull Frame Type/Spacing	*

SCREEN 1-2: SHAPE CHARACTERISTICS

DSP/(.01L)^3	Displacement/Length rat.	57.8%
C.p	Prismatic Coeff	6.0%
C.x	Max Section Coeff	.2%
C.w	Waterplane Coeff	7.7%
L.bp/B.wl	Length/Beam ratio	-17.9%
L.bp/T	Length/Draft ratio	-20.7%
B.wl/T	Beam/Draft ratio	-3.5%
T/D	Draft/Depth ratio	11.6%
L.bp/D	Length/Depth ratio	-11.5%

NOTE: * in difference column indicates that a difference exists for non-numeric items

SCREEN 1-3: SHIP PERFORMANCE

MOBILITY:	
Max Sustained Spd (80% Power)	0.0%
Max Trial Spd (100% Power)	NA
Range @ Endurance Speed	-25.0%
Endurance Period (Fuel @ Endur Spd)	-33.3%
Endurance Period (Stores)	0.0%
Endurance Period (Chilled Stores)	0.0%
Endurance Period (Frozen Stores)	0.0%
Shaft Horsepower Available	25.0%
Shaft Horsepower Req @ Endurance	5.0%
Shaft Horsepower Req @ Sustained	25.0%
HULL EFFICIENCY:	
Drag (sustained spd)	34.4%
Drag (endurance spd)	-9.5%
Bales Rank	106.2%
SURVIVABILITY:	
Blast	
Fragmentation	*
Shock	
NBC	*
Noise Signature	*
IR Signature	
Radar Signature	*

SCREEN 1-4: HM&E SYSTEM SELECTION

MAIN PROPULSION:	
Total Boost Power Avail	22.1%
Boost Reqd at Sustained Spd	25.0%
Boost Growth Potential	13.6%
Boost Engine Type	
Boost Engine Number/Rating	*
Cruise Engine Type	
Cruise Engine Number/Rating	
Transmission Sys Type	

C.6	Outfit & Furn. Related
C.7	Armament Related
C.m	D+C Cost Margin
C.de	Design/Engr (Gp8)
C.con	Constr. Svcs (assy Gp9)
C.pr	Profit
C.csgfe	Combat Systems GFE
C.oth	Total Other Costs
C.HM&E	HM&E GFE
C.pmg	Project Mgr Growth
C.ls	Total Cost Lead Ship
C.bcfs	Basic Const-Follow Ship
C.fs	Total Cost Follow Ship

MISCELLANEOUS INPUTS:

HP.shpi	Total Installed SHP
HP.geni	Total Installed Gen HP
HP.shpe	Propul HP @ Endur. Spd
HP.gene	Gen HP @ avg 24 hr load
SFC.e	Prop SFC @ Endur. Spd
SFCA.e	Gen SFC @ avg 24 hr load
E.gen	KW Rating per Generator
E.24	Avg 24 Hr Elec Load
# lchr	Number of Launchers
# snsr	Number of Sensors
YEAR	Year Commissioned

NOTE: Input Screens 1-3, 1-4, 1-5 directly

SCREEN 1-1:	**COST & SIZE CHARACTERISTICS**	DD963	DDG51	Delta
TOTAL COSTS:	(use lead ship)			
C.bc	Basic Construction Cost			2.0%
C.csgfe	Combat Sytem GFE cost			33.4%
C.oth	Other Costs			2.0%
C.t	Total Ship cost			9.9%
SHIP SIZE:				
DSP.fl	Full Load Displacement			7.9%
DSP.ls	Light Ship Displacement			12.6%
VOL	Total Enclosed Volume			-6.4%
DSP.fl/VOL	Ship Density Full Load			15.3%
DSP.ls/VOL	Ship Density Light Ship			20.3%
L.bp	Length Between Perp.			-11.9%
L.oa	Length Overall			-10.5%
B.wl	Beam at Waterline			7.3%
B.max	Beam (max at deckedge)			21.6%
D	Depth at midships			-.5%
T	Draft (max)			11.1%

V4.2	Propulsor/Transmission
V4.3	Auxiliary Machinery
V4.33	Outside Machy Box Elect.
V5	UNASSIGNED

AREAS:

A2	HUMAN SUPPORT AREA
A2.11+2.211	Officer Living/Messing
A2.12+2.212	CPO Living/Messing
A2.13+2.213	Crew Living/Messing

ENERGY:

Note: for this analysis, use only
10 deg day at Battle condition

E.i	Installed KW
E.t	Maximum KW
E.2	Propulsion KW
E.3	Electrical KW
E.4	Command & Surv KW
E.5	Auxiliary KW
E.6	Outfit and Furn. KW
E.7	Armament KW
E.am	Elec Aquisition Margin
E.slm	Elec Service Life Margin

MANNING:

M.a	Total Accomodations
M.aoff	Officer Accom
M.acpo	CPO Accom
M.aenl	Crew Accom
M.t	Total Complement
M.off	Officer Complement
M.cpo	CPO Complement
M.enl	Crew Complement
M.m	Manning Margin
M.cs	Combat Systems Manning
M.ops	Operations Manning
M.eng	Engr. Manning
M.na	Nav/Admin Manning
M.sup	Supply Manning
M.av	Aviation Manning

COST:

Note: Select Lead Ship for analysis
All Costs x1000

C.1	Structural Related
C.2	Propulsion Related
C.3	Electrical Related
C.4	Command/Surv. Related
C.5	Auxiliary Related

W.64+64+66+67	Crew Related
W.7	ARMAMENT
W.71	Guns and Ammunition
W.72	Missiles and Rockets
W.73 thru 79	Other Armament
W.m	D&C Margin Wt
W.al	Architecural Limit Wt
F1	Crew and Effects Load
F2	Ordnance Load
F23+F26	Aviation Support Load
F4	Fuels/Lubricant Load
F52	Freshwater Load
F3+F5+F6	Other Loads

KG:

KG.ls	Light Ship KG
KG.fl	Full Load KG
KG.m	KG aquisition margin
KG.al	Architectural Limit KG

VOLUMES:

V.hull	Hull Volume
V.dKhs	Deckhouse Volume
V1	MISSION SUPPORT
V1.1	Command, Comm, Surv.
V1.11	Exterior Comms
V1.121	Surface Surveillance
V1.122	Underwater Surveillance
V1.15	Interior Comms
V1.13+1.14 +1.16	Other C&S Volume
V1.2	Weapons
V1.21	Guns
V1.22	Missiles
V1.23	Rockets
V1.24+1.25 +1.26+1.27	Other Armament Vol
V1.3	Aviation
V1.34	Aircraft Stowage
V2	HUMAN SUPPORT
V2.1	Living
V2.2	Commissary
V2.3 Thru 2.7	Other Human Support Vol
V3	SHIP SUPPORT
V3.5	Deck Systems
V3.9	Tanks/Voids
V4	SHIP MOBILITY
V4.1	Propulsion Systems
V4.15	In Machy Box Electric

PRIMARY INPUT SECTION:

		BASELINE DD-963	VARIANT DDG-51
PRIMARY CHARACTERISTICS:			
DSP.FL	Displ Full Load		
DSP.LS	Displ Light Ship		
VOL	Total Volume		
L.BP	Length btwn perp.		
L.OA	Length overall		
B.WL	Beam at waterline		
B.MAX	Beam (max)		
D	Depth.		
T	Draft (max)		
C.P	Prismatic Coef.		
C.X	Max Section Coef.		
C.W	Waterplane Coef.		
WEIGHTS:			
W.1	HULL STRUCTURE		
W.11	Shell/Supports		
W.12+13+14	Struct. blkhds/decks.		
W.15	Deckhouse Struct.		
W.18	Foundation		
W.16+17+19	Other Structure		
W.2	PROPULSION PLANT		
W.23	Propulsion Units		
W.24	Transm/propulsor		
W.25+26+29	Prop.Support		
W.21+22	Other Propulsion		
W.3	ELECTRIC PLANT		
W.31	Elec Power Generation		
W.32	Power Distribution Sys		
W.33	Lighting System		
W.34+39	Elec Support Sys		
W.4	COMMAND AND SURVEILLANCE		
W.43+44	Interior/Exterior Comms		
W.45	Surveillance (surface)		
W.46	Surveillance (subsurf)		
W.41+42+47+ +48+49	Other Command & Surv.		
W.5	AUXILIARY SYSTEMS		
W.51	Climate control		
W.52+53	Seawater/Freshwater sys		
W.56	Ship Control Sys		
W.57+58	Replen/Mech Hndling Sys		
W.54+55+59	Fluid/Misc Support Sys		
W.6	OUTFIT AND FURNISHINGS		
W.61+62+63+69	Non-Crew Related		

from being misled. The "delta" information, however, is included to show that significant differences do exist and can be easily extracted from the raw information for the comparative analysis.

APPENDIX C

DD963 VS DDG51 COMPARISON

An example of a full data base analysis of an existing ship versus a new design. The DD963, at delivery, is compared to the current DDG51 design using a two-ship analysis simulated on a microcomputer spreadsheet.

The initial section of the analysis simulates a data base from which the indices in the screens draw their data. This is similar to the method that would be used if a real data base were available. The reader should note that to prevent the duplication of information, the data for screens 1-3, 1-4 and 1-5 are input directly into the screen and not placed with the simulated data base information. The screens of the spreadsheets have been programmed to draw the data from the data base portion and create the indices in a tabular display. The last column then manipulates the indices to provide the difference or "delta" as explained in section 3.5.

The parameters used for this study are notional and may not totally reflect the current designs. Although every effort was made to obtain the most accurate information available, extreme accuracy was not as important as having sufficient information available to present a good example of how the two-ship analysis is presented and how a comparative analysis would be performed. The input source data is therefore not published to prevent the reader

SCREEN 3-9: COMBAT SYSTEMS BREAKDOWN

COMBAT SYSTEMS WEIGHT:		
W.4/W.csf	Command & Surv Wt	7.0%
W.7/W.csf	Armament Wt	94.1%
W.av/W.csf	Aviation Wt	-100.0%
W.ord/W.csf	Ordnance Wt	149.1%
COMMAND AND SURVEILLANCE WEIGHT:		
W.43+44/W.4	Interior/Exter Comm Wt	17.7%
W.45/W.4	Surface Surv Wt	1004.3%
W.46/W.4	Underwater Surv Wt	-35.9%
W.41+42+47+48+ 49/W.4	Other C&S Wt	2.3%
ARMAMENT WEIGHT:		
W.71/W.7	Guns and Ammo Wt	-44.5%
W.72/W.7	Missiles/Rockets Wt	359.6%
W.73thru79/W.7	Other Armament Wt	59.7%
COMBAT SYSTEMS VOLUME:		
V1.1/V1	Command and Surv Volume	16.8%
V1.2/V1	Armament Volume	24.3%
V1.3/V1	Aviation Volume	-92.6%
COMMAND AND SURVEILLANCE VOLUME:		
V1.11+ 1.15/V1.1	Interior/Exter Comm Vol	20.0%
V1.121/V1.1	Surface Surv Vol	238.6%
V1.122/V1.1	Underwater Surv Vol	21.5%
V1.13+1.14+ 1.16/V1.1	Other C&S Vol	-7.9%
ARMAMENT VOLUME:		
V1.21/V1.2	Guns & Ammo Vol	-6.0%
V1.22+ 1.23/V1.2	Missiles/Rockets Vol	81.2%
V1.24+1.25+ 1.26+1.27/V1.2	Other Armament Vol	-40.3%

SCREEN 3-10: COMBAT SYSTEMS INDICES

COMBAT SYSTEMS DRIVERS:		
W.7/DSP.FL	Armament Wt Fraction	94.1%
#L/DSP.FL	Armament Cap Size Ratio	-7.3%
W.7/#L	Armament Spec Wt	94.1%
W.4/DSP.FL	C&S Weight Fraction	7.0%
#S/DSP.FL	C&S Capacity Size Ratio	11.2%
W.4/#S	C&S Specific Wt	-10.8%
RELATED COMBAT SYSTEM RATIOS:		
W.csf/V1	Combat System Density	66.4%
W.4/V1.1	Command & Surv Density	-8.3%
W.7/V1.2	Armament Density	56.2%
E.cs/W.csf	Combat Sys KW/Wt Ratio	5.8%
C.cs/W.csf	Combat Sys Cost/Wt Ratio	-18.5%

SCREEN 3-11: HUMAN SUPPORT BREAKDOWN

WEIGHT:		
W.ce/W.HS	Crew and Effects Wt	15.2%
W.6cr/W.HS	Outfit & Furn Wt	51.8%
W.pw/W.HS	Potable Water Wt	11.9%
VOLUME:		
V2.1/V2	Living Volume	-15.8%
V2.2/V2	Food Svs/Mess/Lounge Vol	-12.3%
V2.3thru2.7/V2	Medical/Gen/Other Vol	51.4%

SCREEN 3-12: HUMAN SUPPORT IND'CES

HUMAN SUPPORT DRIVERS:		
W.HS/DSP.FL	Human Support Wt Frac	38.0%
W.HS/M.a	Human Support Spec Wt	22.1%
M.a/DSP.FL	Total Accom Ship Size Ra	4.7%
RELATED HUMAN SUPPORT RATIOS:		
W.HS/V2	Human Support Density	47.5%
V2.1/M.a	Persnl Living Spec Vol	-25.5%
V2/M.a	Human Support Spec Vol	-17.2%
A2/M.a	Human Support Spec Area	-21.3%
A2.11+2.211/ M.aoff	Officer Lvng Area/Man	-17.3%
A2.12+2.212/ M.acpo	CPO Living Area/Man	-23.9%
A2.13+2.213/ M.aenl	Enlisted Lvng Area/Man	-48.2%
M.aoff/DSP.FL	Officer Ship Size Ratio	-7.3%
M.acpo/DSP.FL	CPO Ship Size Ratio	5.9%
M.aenl/DSP.FL	Enlisted Ship Size Ratio	5.8%

SCREEN 3-13: MARGIN SUMMARY

WEIGHT:		
W.m/(Dls-W.m)	Acquisition Margin NAVSEA Standard	8.5%
(W.al-Dfl)/Dfl	Service Life Margin NAVSEA Standard	8.5%
KG:		
KG.m/KG.ls	Acquisition Margin NAVSEA Standard	5.0%
(KG.al-KG.fl) /KG.fl	Service Life Margin NAVSEA Standard	-29.4%
ELECTRIC POWER:		
E.m/E.t	Acquisition Margin NAVSEA Standard	18.1%
E.slm/(E.t-E.2 +E.ma+E.slm)	Service Life Margin NAVSEA Standard	-.2%

VOLUME:		
V.5/VOL	Service Life Margin NAVSEA Standard	-90.3%
MANNING:		
(M.a-M.t)/M.t	Service Life Margin NAVSEA Standard	15.4%

APPENDIX D

ASSET BASELINE VS NEW TECHNOLOGY VARIANT COMPARISON

This appendix presents an example of how the two ship analysis would differ if the Advanced Surface Ship Evaluation Tool were used to perform a new technology tradeoff study. In this case, a new technology frigate developed by Goddard in reference (41) was used as the baseline. A variant was created by holding performance constant and changing the main propulsion system from the standard LM2500-30 to an Intercooled Regenerative Gas Turbine (IRGT) system. The output from ASSET was then used for both ships and placed into a spreadsheet data base to simulate the two-ship technology tradeoff comparison discussed in chapter 3.

This study should convince the reader that ASSET already supports the greater majority of the indices selected for analysis by the author. The only serious shortcomings appear in the area of electrical, auxiliaries and survivability. The basic methodology, however, is not impacted and a satisfactory analysis can be easily obtained, as shown in the study performed in section 3.5.3.1.

All parameters were obtained from either the output or the MPL of ASSET. Some output was modified, as discussed in appendix B, to obtain the proper comparative analysis parameter used in this methodology. These changes were made manually outside the realm of the spreadsheet. The existing logic and calculations of ASSET could be easily modified to implement these changes internally in the program.

Those input parameters and their associated indices not supported by ASSET are listed as "NA" and cannot be implemented in the existing versions of ASSET. The recommended method of interfacing the comparative analysis methodology to the ASSET program is discussed further in chapter 7.

PRIMARY INPUT SECTION:

		BASELINE TECH BASE	VARIANT IRGT VAR
PRIMARY CHARACTERISTICS:			
DSP.FL	Displ Full Load	5537.3	5328.5
DSP.LS	Displ Light Ship	4260.1	4274.0
VOL	Total Volume	658118.0	650232.0
L.BP	Length btwn perp.	425.0	410.0
L.OA	Length overall	NA	NA
B.WL	Beam at waterline	50.0	50.8
B.MAX	Beam (max)	NA	NA
D	Depth.	38.0	38.0
T	Draft (max)	18.8	18.5
C.P	Prismatic Coef.	.600	.600
C.X	Max Section Coef.	.803	.803
C.W	Waterplane Coef.	.798	.805
WEIGHTS:			
W.1	HULL STRUCTURE	1300.7	1289.7
W.11	Shell/Supports	383.5	373.9
W.12+13+14	Struct. blkhds/decks.	481.3	486.1
W.15	Deckhouse Struct.	156.5	155.9
W.18	Foundation	224.9	230.0
W.16+17+19	Other Structure	54.5	53.9
W.2	PROPULSION PLANT	429.6	464.7
W.23	Propulsion Units	203.8	242.0
W.24	Transm/propulsor	125.2	121.6
W.25+26+29	Prop.Support	100.7	101.1
W.21+22	Other Propulsion	0.0	0.0
W.3	ELECTRIC PLANT	248.4	251.2
W.31	Elec Power Generation	94.7	94.7
W.32	Power Distribution Sys	91.3	94.4
W.33	Lighting System	20.9	20.6
W.34+39	Elec Support Sys	41.5	41.5
W.4	COMMAND AND SURVEILLANCE	649.6	648.5
W.43+44	Interior/Exterior Comms	39.1	38.7
W.45	Surveillance (surface)	5.9	5.9
W.46	Surveillance (subsurf)	350.0	350.0
W.41+42+47+ +48+49	Other Command & Surv.	254.6	253.9
W.5	AUXILIARY SYSTEMS	634.6	624.1
W.51	Climate control	148.7	147.2
W.52+53	Seawater/Freshwater sys	128.0	126.9
W.56	Ship Control Sys	91.0	88.3
W.57+58	Replen/Mech Hndling Sys	109.2	107.9
W.54+55+59	Fluid/Misc Support Sys	157.6	153.8
W.6	OUTFIT AND FURNISHINGS	394.0	391.0
W.61+62+63+69	Non-Crew Related	220.7	217.8
W.64+64+66+67	Crew Related	173.3	173.2

W.7	ARMAMENT	130.0	130.0
W.71	Guns and Ammunition	45.9	45.9
W.72	Missiles and Rockets	78.2	78.2
W.73 thru 79	Other Armament	5.9	5.9
W.m	D & C Margin Weight	473.3	475.0
W.al	Architecural Limit Wt	NA	NA
F1	Crew and Effects Load	33.9	33.9
F2	Ordnance Load	144.2	144.2
F23+F26	Aviation Support Load	50.7	50.7
F4	Fuels/Lubricant Load	1006.6	783.9
F52	Freshwater Load	44.7	44.7
F3+F5+F6	Other Loads	92.6	92.6
KG:			
KG.ls	Light Ship KG	NA	NA
KG.fl	Full Load KG	21.79	22.36
KG.m	KG aquisition margin	NA	NA
KG.al	Architectural Limit KG	NA	NA
VOLUMES:			
V.hull	Hull Volume	550657.0	543075.0
V.dkhs	Deckhouse Volume	107462.0	107150.0
V1	MISSION SUPPORT	148287.5	148339.9
V1.1	Command, Comm, Surv.	62082.7	62144.2
V1.11	Exterior Comms	4590.0	4590.0
V1.121	Surface Surveillance	3400.0	3400.0
V1.122	Underwater Surveillance	29707.5	29707.5
V1.15	Interior Comms	3859.8	3813.9
V1.13+1.14 +1.16	Other C&S Volume	20524.1	20632.9
V1.2	Weapons	20754.4	18988.7
V1.21	Guns	4896.0	4896.0
V1.22	Missiles	14093.0	14093.0
V1.23	Rockets	0.0	0.0
V1.24+1.25 +1.26+1.27	Other Armament Vol	1765.4	1756.7
V1.3	Aviation	65450.1	65450.0
V1.34	Aircraft Stowage	53550.0	53550.0
V2	HUMAN SUPPORT	131590.5	131588.1
V2.1	Living	80054.2	80052.7
V2.2	Commissary	36461.7	36461.0
V2.3 Thru 2.7	Other Human Support Vol	15074.6	15075.1
V3	SHIP SUPPORT	200219.4	189093.5
V3.5	Deck Systems	7912.7	7784.3
V3.9	Tanks/Voids	61760.9	51952.3
V4	SHIP MOBILITY	177723.9	179494.3
V4.1	Propulsion Systems	133591.1	135591.0
V4.15	In Machy Box Electric	NA	NA
V4.2	Propulsor/Transmission	NA	NA

V4.3	Auxiliary Machinery	23623.2	23393.7
V4.33	Outside Machy Box Elect.	20509.7	20509.7
V5	UNASSIGNED	0.0	0.0
AREAS:			
A2	HUMAN SUPPORT AREA	15481.0	15481.0
A2.11+2.211	Officer Living/Messing	3153.0	3153.0
A2.12+2.212	CPO Living/Messing	1312.9	1312.9
A2.13+2.213	Crew Living/Messing	7208.0	7208.0
ENERGY:			
Note: for this analysis, use only 10 deg day at Battle condition			
E.i	Installed KW	6000.0	6000.0
E.t	Maximum KW	2841.0	2824.0
E.2	Propulsion KW	NA	NA
E.3	Electrical KW	NA	NA
E.4	Command & Surv KW	NA	NA
E.5	Auxiliary KW	NA	NA
E.6	Outfit and Furn. KW	NA	NA
E.7	Armament KW	NA	NA
E.am	Elec Aquisition Margin	500.0	497.0
E.slm	Elec Service Life Margin	709.0	729.0
MANNING:			
M.a	Total Accomodations	301	301
M.aoff	Officer Accom	29	29
M.acpo	CPO Accom	21	21
M.aenl	Crew Accom	251	251
M.t	Total Complement	273	268
M.off	Officer Complement	26	24
M.cpo	CPO Complement	19	19
M.enl	Crew Complement	228	225
M.m	Manning Margin	28	33
M.cs	Combat Systems Manning	62	60
M.ops	Operations Manning	65	64
M.eng	Engr. Manning	50	48
M.na	Nav/Admin Manning	19	19
M.sup	Supply Manning	35	35
M.av	Aviation Manning	42	42
COST:			
Note: Select Lead Ship for analysis All Costs x1000			
C.1	Structural Related	12125.0	12046.0
C.2	Propulsion Related	40710.0	43401.0
C.3	Electrical Related	16256.0	16423.0
C.4	Command/Surv. Related	26668.0	26640.0
C.5	Auxiliary Related	32281.0	31865.0

C.6	Outfit & Furn. Related	15307.0	15214.0
C.7	Armament Related	1465.0	1465.0
C.m	D+C Cost Margin	18012.0	18382.0
C.de	Design/Engr (Gp8)	255434.0	259783.0
C.con	Constr. Svcs (assy Gp9)	40948.0	41479.0
C.pr	Profit	36744.0	37336.0
C.csgfe	Combat Systems GFE	307900.0	307900.0
C.oth	Total Other Costs	146332.0	148690.0
C.HM&E	HM&E GFE	19841.6	20161.0
C.pmg	Project Mgr Growth	29762.4	30242.0
C.ls	Total Cost Lead Ship	970115.0	980787.0
C.bcfs	Basic Const-Follow Ship	237445.0	241063.0
C.fs	Total Cost Follow Ship	583691.0	588377.0

MISCELLANEOUS INPUTS:

HP.shpi	Total Installed SHP	52500	52500
HP.geni	Total Installed Gen HP	NA	NA
HP.shpe	Propul HP @ Endur. Spd	9861	10064
HP.gene	Gen HP @ avg 24 hr load	3651	3627
SFC.e	Prop SFC @ Endur. Spd	.544	.343
SFCA.e	Gen SFC @ avg 24 hr load	.693	.694
E.gen	KW Rating per Generator	1500	1500
E.24	Avg 24 Hr Elec Load	2669	2652
# lchr	Number of Launchers	5	5
# snsr	Number of Sensors	7	7
YEAR	Year Commissioned (IOC)	2005	2005

NOTE: Input Screens 1-3, 1-4, 1-5 directly

		TECH BASE	IRGT VAR	Delta
SCREEN 1-1:	**COST & SIZE CHARACTERISTICS**			
TOTAL COSTS:	(use lead ship)			
C.bc	Basic Construction Cost	495950.0	504034.0	1.6%
C.csgfe	Combat Sytem GFE cost	307900.0	307900.0	0.0%
C.oth	Other Costs	146332.0	148690.0	1.6%
C.t	Total Ship cost	970115.0	980787.0	1.1%
SHIP SIZE:				
DSP.fl	Full Load Displacement	5537.3	5328.5	-3.8%
DSP.ls	Light Ship Displacement	4260.1	4274.0	.3%
VOL	Total Enclosed Volume	658118.0	650232.0	-1.2%
DSP.fl/VOL	Ship Density Full Load	18.8	18.4	-2.6%
DSP.ls/VOL	Ship Density Light Ship	14.5	14.7	1.5%
L.bp	Length Between Perp.	425.0	410.0	-3.5%
L.oa	Length Overall	NA	NA	NA
B.wl	Beam at Waterline	50.0	50.8	1.6%
B.max	Beam (max at deckedge)	NA	NA	NA
D	Depth at midships	38.0	38.0	0.0%
T	Draft (max)	18.8	18.5	-1.3%

SCREEN 1-2: SHAPE CHARACTERISTICS

DSP/(.01L)^3	Displacement/Length rat.	72.1	77.3	7.2%
C.p	Prismatic Coeff	.600	.600	0.0%
C.x	Max Section Coeff	.803	.803	0.0%
C.w	Waterplane Coeff	.798	.805	.9%
L.bp/B.wl	Length/Beam ratio	8.50	8.07	-5.0%
L.bp/T	Length/Draft ratio	22.67	22.16	-2.2%
B.wl/T	Beam/Draft ratio	2.67	2.75	3.0%
T/D	Draft/Depth ratio	.49	.49	-1.3%
L.bp/D	Length/Depth ratio	11.18	10.79	-3.5%

NOTE: * in difference column indicates that a difference exists for non-numeric items

SCREEN 1-3: SHIP PERFORMANCE

MOBILITY:			
Max Sustained Spd (80% Power)	27.9	27.5	-1.4%
Max Trial Spd (100% Power)	29.0	28.7	-1.0%
Range @ Endurance Speed	4500	4500	0.0%
Endurance Period (Fuel @ Endur Spd)	9.4	9.4	0.0%
Endurance Period (Stores)	45.0	45.0	0.0%
Endurance Period (Chilled Stores)	30.0	30.0	0.0%
Endurance Period (Frozen Stores)	45.0	45.0	0.0%
Shaft Horsepower Available	52500	52500	0.0%
Shaft Horsepower Req @ Endurance	9861	10064	2.1%
Shaft Horsepower Req @ Sustained	42011	42000	-.0%
HULL EFFICIENCY:			
Drag (sustained spd)	332156	335576	1.0%
Drag (endurance spd)	101383	103483	2.1%
Bales Rank	9.31	8.96	-3.8%
SURVIVABILITY:			
Blast	NA	NA	
Fragmentation	NA	NA	
Shock	NA	NA	
NBC	NA	NA	
Noise Signature	NA	NA	
IR Signature	NA	NA	
Radar Signature	NA	NA	

SCREEN 1-4: HM&E SYSTEM SELECTION

MAIN PROPULSION:			
Total Boost Power Avail	52500.0	52500.0	0.0%
Boost Reqd at Sustained Spd	42011.0	42000.0	-.0%
Boost Growth Potential	10489.0	10500.0	.1%
Boost Engine Type	GT	IRGT	*
Boost Engine Number/Rating	2/26250	2/26250	
Cruise Engine Type	-	-	
Cruise Engine Number/Rating	-	-	
Transmission Sys Type	AC/AC	AC/AC	

Propeller Type	FP	FP	
Propeller Number/RPM	2/140	2/140	
Propeller Open Wtr Effy (sustained)	.750	.748	-.3%
Propeller Open Wtr Effy (endurance)	.780	.780	0.0%
Propulsion Coefficient (PC)	.718	.716	-.3%
SFC @ Endurance Spd	.544	.343	-36.9%
SFC @ Sustained Spd	.433	.330	-23.8%
Other			
ELECTRIC POWER:			
Total 60 Hz Available	6000.0	6000.0	0.0%
Total 60 Hz Max Load	2841.0	2824.0	-.6%
60 Hz Growth Potential (all Gen)	3159.0	3176.0	.5%
Total 400 Hz Available	NA	NA	NA
Total 400 Hz Max Load	NA	NA	NA
400 Hz Growth Potential	NA	NA	NA
60 Hz Generator Type	GT	GT	
60 Hz Generator Number/Rating	4/1500	4/1500	
400 Hz Converter Type	NA	NA	
400 Hz Converter Number/Rating	NA	NA	
SFCA	.693	.693	0%
Other			
AUXILIARY:			
Total AC Available	NA	NA	NA
AC Maximum Load	NA	NA	NA
AC Growth Potential	NA	NA	NA
AC Type	NA	NA	
AC Number/Rating	NA	NA	
Heating Type	NA	NA	
Heating Rating	NA	NA	
Firepump Type	NA	NA	
Firepump No./Rating	NA	NA	
Seawater Pump Type	NA	NA	
Seawater Pump No./Rating	NA	NA	
HP Air Compressor Type	NA	NA	
HP Air Compressor No./Rating	NA	NA	
LP Air Compressor Type	NA	NA	
LP Air Compressor No./Rating	NA	NA	
Distilling Plant Type	NA	NA	
Distilling Plant No./Rating	NA	NA	
Boats Type/No.	NA	NA	
Steering Units Type/No.	NA	NA	
Anchors Type/No.	NA/2	NA/2	
Anchors Length of Chain	NA	NA	
UNREP Capability	STREAM	STREAM	
Other			
STRUCTURE/MATERIALS:			
Hull Materials (array)	HTS	HTS	
Deckhouse Materials (array)	HTS	HTS	
Hull Frame Type/Spacing	TRANS/4.0	TRANS/4.0	

Deckhouse Frame Type/Spacing	NA	NA
Other		
DECK HEIGHTS:		
Number internal decks in hull	4	4
Number internal decks in deckhouse	3	3
Internal Deck Heights (array above BL)	4.0	4.0
	12.5	12.5
	21.0	21.0
	29.5	29.5
Hull Avg Deck Height	8.5	8.5
Other		
MANNING:		
Total Accom/Complement/Growth Pot.	301/273/28	301/268/33
Total Complement (OFF/CPO/ENL)	26/19/228	24/19/225
Habitability Classification	MODERN	MODERN
Flag Configured	NO	NO
Other		

SCREEN 1-5: COMBAT SYSTEMS SELECTION

ANTI-AIR WARFARE:		
Armament	1-76mm Gun	1-76mm Gun
	2-20mm CIWS	2-20mm CIWS
	VLS Seasp.	VLS Seasp.
Sensors	MK92 FCS	MK92 FCS
	IR DETECTOR	IR DETECTOR
Aviation Capabilities	3-Lamps III	3-Lamps III
ANTI-SUBMARINE WARFARE:		
Armament	VLS ASROC	VLS ASROC
	2-TT MK32	2-TT MK32
Sensors	CA Sonar	CA Sonar
	Towed Array	Towed Array
Aviation Capabilities	3-Lamps III	3-Lamps III
SURFACE/STRIKE WARFARE:		
Armament	1-76mm Gun	1-76mm Gun
	VLS Harpoon	VLS Harpoo
Sensors	Nav Radar	Nav Radar
	Surf Radar	Surf Radar
Aviation Capabilities	3-Lamps III	3-Lamps III
COMMAND/CONTROL/COMM/INTEL:		
Communications	Ext Comms	Ext Comms
Electronic Warfare	Active ECM	Active ECM
	Acous Decoy	Acous Decoy
	SRBOC	SRBOC

Control		C/C Suite	C/C Suite	
SCREEN 2-1: SWBS WEIGHT FRACTIONS				
LIGHT SHIP:				
W.1/DSP.LS	Structural	30.5%	30.2%	-.8%
W.2/DSP.LS	Main Propulsion	10.1%	10.9%	8.2%
W.3/DSP.LS	Electrical	5.8%	5.9%	1.1%
W.4/DSP.LS	Command & Surveillance	15.2%	15.2%	-.2%
W.5/DSP.LS	Auxiliary	14.9%	14.6%	-1.7%
W.6/DSP.LS	Outfit & Furnishings	9.2%	9.1%	-.8%
W.7/DSP.LS	Armament	3.1%	3.0%	0.0%
W.m/DSP.LS	Margin	11.1%	11.1%	.4%
FULL LOAD:				
W.1/DSP.FL	Structural	23.5%	24.2%	-.8%
W.2/DSP.FL	Main Propulsion	7.8%	8.7%	8.2%
W.3/DSP.FL	Electrical	4.5%	4.7%	1.1%
W.4/DSP.FL	Command & Surveillance	11.7%	12.2%	-.2%
W.5/DSP.FL	Auxiliary	11.5%	11.7%	-1.7%
W.6/DSP.FL	Outfit & Furnishings	7.1%	7.3%	-.8%
W.7/DSP.FL	Armament	2.3%	2.4%	0.0%
W.m/DSP.FL	Margin	8.5%	8.9%	.4%
SCREEN 2-2: LOAD WEIGHT FRACTIONS				
W.fuel/W.ld	Liquid (fuel & Lube)	78.8%	74.3%	-22.1%
W.ce/W.ld	Crew and Effects	2.7%	3.2%	0.0%
W.ord/W.ld	Ordnance	7.3%	8.9%	0.0%
W.av/W.ld	Aviation	4.0%	4.8%	0.0%
W.oth/W.ld	Others	7.2%	8.8%	0.0%
W.ld/DSP.FL	Load to Full Load ratio	23.1%	19.8%	-17.4%
DSP.ls/DSP.fl	Lightship to Full ratio	76.9%	80.2%	.3%
SCREEN 2-3: FUNCTIONAL WT. ALLOCATION				
W.csl/DSP.LS	LS Combat Sys Weight	20.6%	20.5%	-.1%
W.mal/DSP.LS	LS Machinery Weight	34.7%	35.3%	2.1%
W.cl/DSP.LS	LS Containment Weight	44.8%	44.2%	-.8%
W.csf/DSP.FL	FL Combat Sys Weight	18.4%	19.1%	-.1%
W.maf/DSP.FL	FL Machinery Weight	44.8%	43.0%	-7.7%
W.cf/DSP.FL	FL Containment Weight	36.7%	37.9%	-.8%
SCREEN 2-4: SSCS VOLUME FRACTIONS				
V1/VOL	Mission Support	22.5%	22.8%	.0%
V2/VOL	Human Support	20.0%	20.2%	-.0%
V3/VOL	Ship Support	30.4%	29.1%	-5.6%
V4/VOL	Ship Mobility	27.0%	27.6%	1.0%
V5/VOL	Unassigned	0.0%	0.0%	0.0%

SCREEN 2-5: SPACE TYPE/LOCATION VOLUME

V.hull/VOL	Hull Volume	83.7%	83.5%	-1.4%
V.dh/VOL	Deckhouse Volume	16.3%	16.5%	-.3%
V.tk/VOL	Tankage/Void Volume	9.4%	8.0%	-15.9%
V.lo/VOL	Large Space Volume	31.6%	32.0%	.1%
V.a/VOL	Arrangeable Volume	59.0%	60.0%	.4%

SCREEN 2-6: FUNCTIONAL VOLUME ALLOCATION

V.cs/VOL	Combat Sys Volume	22.5%	22.8%	.0%
V.ma/VOL	Machinery Related Vol	37.6%	36.8%	-3.3%
V.c/VOL	Containment Volume	39.8%	40.1%	-.5%
V.5/VOL	Unassigned Volume	0.0%	0.0%	0.0%

SCREEN 2-7: ELECTRICAL ENERGY ALLOCATION

Note: max load/ 10 deg day/Battle				
E2/E	Propulsion Plant	NA	NA	NA
E3/E	Electric Plant	NA	NA	NA
E4/E	Command and Surveillance	NA	NA	NA
E5/E	Auxiliary	NA	NA	NA
E6/E	Outfit & Furnishings	NA	NA	NA
E7/E	Armament	NA	NA	NA
Em/E	Margin (Acq.+Serv Life)	NA	NA	
Note: installed load/10 deg/Battle				
E2/E	Propulsion Plant	NA	NA	NA
E3/E	Electric Plant	NA	NA	NA
E4/E	Command and Surveillance	NA	NA	NA
E5/E	Auxiliary	NA	NA	NA
E6/E	Outfit & Furnishings	NA	NA	NA
E7/E	Armament	NA	NA	NA
Em/E	Margin	29.9%	30.3%	1.4%

SCREEN 2-8: FUNCTIONAL ENERGY ALLOCATION

INSTALLED HP:				
HP.shpi/HP.t	Propulsion HP Allocation	NA	NA	NA
HP.geni/HP.t	Electrical HP Allocation	NA	NA	NA
FUEL USAGE:				
FF.mp/FF.t	Propulsion Fuel Alloc.	68.0%	57.8%	-35.7%
FF.gen/FF.t	Electrical Fuel Alloc.	32.0%	42.2%	-.5%
ELECTRICAL:				
Note: max load/10deg day/Battle				
E.cs/E.t	Combat System Elec	NA	NA	NA
E.ma/E.t	Machinery Elec	NA	NA	NA
E.c/E.t	Containment Elec	NA	NA	NA
Note: instal load/10deg day/Battle				
E.cs/E.i	Combat System Elec	NA	NA	NA
E.ma/E.i	Machinery Elec	NA	NA	NA
E.c/E.i	Containment Elec	NA	NA	NA

W2 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL	SHP INS	SHP/DSP
	(tons)	(SHP)	(HP/ton)
FF-1006	1923	20000	10.4
FF-1033	1698	9200	5.4
FF-1037	2537	20000	7.9
FF-1040	3469	35000	10.1
FF-1052	4014	35000	8.7
FFG-7	3782	40000	10.6
DD-692	3193	60000	18.8
DD-931	3925	70000	17.8
DD-963	7696	80000	10.4
DDG-2	4505	70000	15.5
DDG-37	5563	85000	15.3
DDG-993	9029	80000	8.9
DDG-51	8369	100000	11.9
CG-26	7839	85000	10.8
CG-47	9614	80000	8.3

W1 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL	VOL	DSP/VOL
	(tons)	(ft^3)	(lbs/ft^3)
FF-1006	1923	199486	21.6
FF-1033	1698	242397	15.7
FF-1037	2537	290396	19.6
FF-1040	3469	407617	19.1
FF-1052	4014	503403	17.9
FFG-7	3782	531178	15.9
DD-692	3193	289030	24.7
DD-931	3925	414393	21.2
DD-963	7696	1034908	16.7
DDG-2	4505	484897	20.8
DDG-37	5563	639470	19.5
DDG-993	9029	1065367	19.0
DDG-51	8369	964013	19.4
CG-26	7839	857400	20.5
CG-47	9614	1102513	19.5

<u>HUMAN SUPPORT SPECIFIC VOLUME</u>
<u>HISTORIC TREND DATA</u>

SHIP	HS SPEC VOL (ft^3/man)
FF-1006	380.67
FF-1033	421.44
FF-1037	369.35
FF-1040	362.52
FF-1052	440.95
FFG-7	569.95
DD-692	232.90
DD-931	335.72
DD-963	635.16
DDG-2	365.10
DDG-37	381.31
DDG-993	543.00
DDG-51	488.62
CG-26	428.57
CG-47	477.97

COMBAT SYSTEM WEIGHT FRACTION
TIME HISTORY TREND DATA

SHIP	CS WT FRAC
FF-1006	.096
FF-1033	.084
FF-1037	.098
FF-1040	.093
FF-1052	.107
FFG-7	.069
DD-692	.164
DD-931	.132
DD-963	.076
DDG-2	.118
DDG-37	.111
DDG-993	.093
DDG-51	.107
CG-26	.121
CG-47	.102

PROPULSION AND ELECTRIC PLANT RELATED TIME HISTORY TREND DATA

SHIP	SHP RATIO (HP/ton)	KW RATIO (KW/ton)
FF-1006	10.40	.390
FF-1033	5.42	.589
FF-1037	7.88	.788
FF-1040	10.09	.577
FF-1052	8.72	.747
FFG-7	10.58	.793
DD-692	18.79	.313
DD-931	17.83	.637
DD-963	10.40	.780
DDG-2	15.54	.444
DDG-37	15.28	.719
DDG-993	8.86	.665
DDG-51	11.95	.896
CG-26	10.84	.880
CG-47	8.32	.780

FULL LOAD DISPLACEMENT, VOLUME, SHIP DENSITY
TIME HISTORY TREND DATA

SHIP	DSP.FL	VOL	SHIP DENSITY
	(tons)	(ft3)	(lbs/ft3)
FF-1006	1923	199486	21.59
FF-1033	1698	242397	15.69
FF-1037	2537	290396	19.57
FF-1040	3469	407617	19.06
FF-1052	4014	503403	17.86
FFG-7	3782	531178	15.95
DD-692	3193	289030	24.75
DD-931	3925	414393	21.22
DD-963	7696	1034908	16.66
DDG-2	4505	484897	20.81
DDG-37	5563	639470	19.49
DDG-993	9029	1065367	18.98
DDG-51	8369	964013	19.45
CG-26	7839	857400	20.48
CG-47	9614	1105513	19.48

COMMISSIONING DATES OF SHIPS IN DATA BASE

SHIP	YEAR COMMISSIONED
FF-1006	1952
FF-1033	1959
FF-1037	1963
FF-1040	1964
FF-1052	1969
FFG-7	1977
DD-692	1943
DD-931	1955
DD-963	1975
DDG-2	1960
DDG-37	1961
DDG-993	1982
DDG-51	1989
CG-26	1967
CG-47	1982

APPENDIX E

TREND COMPARATIVE ANALYSIS DATA BASE

This appendix includes some representative data points of the initial ships selected for historical trend display for the Trend Analysis option of the comparative analysis model. Complex indices, are included for time history and triple plots.

These points should be placed in the data base directly for automatic recall when the user selects the appropriate trend chart. The same parameter or indice from the new ship under investigation may then be plotted with the historical data for comparison. The detailed methodology is discussed in chapter 5.

VOLUME:				
V.5/VOL	Service Life Margin	0.0%	0.0%	0.0%
	NAVSEA Standard	0.0%	0.0%	
MANNING:				
(M.a-M.t)/M.t	Service Life Margin	10.3%	12.3%	17.9%
	NAVSEA Standard	10.0%	10.0%	

SCREEN 3-11: HUMAN SUPPORT BREAKDOWN

WEIGHT:				
W.ce/W.HS	Crew and Effects Wt	13.5%	13.5%	0.0%
W.6cr/W.HS	Outfit & Furn Wt	68.8%	68.8%	-.1%
W.pw/W.HS	Potable Water Wt	17.7%	17.8%	0.0%
VOLUME:				
V2.1/V2	Living Volume	60.8%	60.8%	-.0%
V2.2/V2	Food Svs/Mess/Lounge Vol	27.7%	27.7%	-.0%
V2.3thru2.7/V2	Medical/Gen/Other Vol	11.5%	11.5%	.0%

SCREEN 3-12: HUMAN SUPPORT INDICES

HUMAN SUPPORT DRIVERS:				
W.HS/DSP.FL	Human Support Wt Frac	4.5%	4.7%	-.0%
W.HS/M.a	Human Support Spec Wt	.837	.837	-.0%
M.a/DSP.FL	Total Accom Ship Size Ra	54.4	56.5	3.9%
RELATED HUMAN SUPPORT RATIOS:				
W.HS/V2	Human Support Density	4.288	4.286	-.0%
V2.1/M.a	Persnl Living Spec Vol	266.0	266.0	-.0%
V2/M.a	Human Support Spec Vol	437.2	437.2	-.0%
A2/M.a	Human Support Spec Area	51.4	51.4	0.0%
A2.11+2.211/ M.aoff	Officer Lvng Area/Man	108.7	108.7	0.0%
A2.12+2.212/ M.acpo	CPO Living Area/Man	62.5	62.5	0.0%
A2.13+2.213/ M.aenl	Enlisted Lvng Area/Man	28.7	28.7	0.0%
M.aoff/DSP.FL	Officer Ship Size Ratio	5.24	5.44	3.9%
M.acpo/DSP.FL	CPO Ship Size Ratio	3.79	3.94	3.9%
M.aenl/DSP.FL	Enlisted Ship Size Ratio	45.33	47.11	3.9%

SCREEN 3-13: MARGIN SUMMARY

WEIGHT:				
W.m/(Dls-W.m)	Acquisition Margin	12.5%	12.5%	.4%
	NAVSEA Standard	10.0%	10.0%	
(W.al-Dfl)/Dfl	Service Life Margin	NA	NA	NA
	NAVSEA Standard	10.0%	10.0%	
KG:				
KG.m/KG.ls	Acquisition Margin	NA	NA	NA
	NAVSEA Standard	10.0%	10.0%	
(KG.al-KG.fl) /KG.fl	Service Life Margin	NA	NA	NA
	NAVSEA Standard	4.6%	4.5%	
ELECTRIC POWER:				
E.m/E.t	Acquisition Margin	17.6%	17.6%	-.0
	NAVSEA Standard	20.0%	20.0%	
E.slm/(E.t-E.2 +E.ma+E.slm)	Service Life Margin	17.5%	18.0%	2.8%
	NAVSEA Standard	20.0%	20.0%	

SCREEN 3-9: COMBAT SYSTEMS BREAKDOWN

COMBAT SYSTEMS WEIGHT:				
W.4/W.csf	Command & Surv Wt	70.3%	70.3%	-.2%
W.7/W.csf	Armament Wt	14.1%	14.1%	0.0%
W.av/W.csf	Aviation Wt	5.5%	5.5%	0.0%
W.ord/W.csf	Ordnance Wt	10.1%	10.1%	0.0%
COMMAND AND SURVEILLANCE WEIGHT:				
W.43+44/W.4	Interior/Exter Comm Wt	6.0%	6.0%	-1.0%
W.45/W.4	Surface Surv Wt	.9%	.9%	0.0%
W.46/W.4	Underwater Surv Wt	53.9%	54.0%	0.0%
W.41+42+47+48+ 49/W.4	Other C&S Wt	39.2%	39.2%	-.3%
ARMAMENT WEIGHT:				
W.71/W.7	Guns and Ammo Wt	35.3%	35.3%	0.0%
W.72/W.7	Missiles/Rockets Wt	60.2%	60.2%	0.0%
W.73thru79/W.7	Other Armament Wt	4.5%	4.5%	0.0%
COMBAT SYSTEMS VOLUME:				
V1.1/V1	Command and Surv Volume	41.9%	41.9%	.1%
V1.2/V1	Armament Volume	14.0%	12.8%	-8.5%
V1.3/V1	Aviation Volume	44.1%	44.1%	-.0%
COMMAND AND SURVEILLANCE VOLUME:				
V1.11+ 1.15/V1.1	Interior/Exter Comm Vol	13.6%	13.5%	-.5%
V1.121/V1.1	Surface Surv Vol	5.5%	5.5%	0.0%
V1.122/V1.1	Underwater Surv Vol	47.9%	47.8%	0.0%
V1.13+1.14+ 1.16/V1.1	Other C&S Vol	33.1%	33.2%	.5%
ARMAMENT VOLUME:				
V1.21/V1.2	Guns & Ammo Vol	23.6%	25.8%	0.0%
V1.22+ 1.23/V1.2	Missiles/Rockets Vol	67.9%	74.2%	0.0%
V1.24+1.25+ 1.26+1.27/V1.2	Other Armament Vol	8.5%	9.3%	-.5%

SCREEN 3-10: COMBAT SYSTEMS INDICES

COMBAT SYSTEMS DRIVERS:				
W.7/DSP.FL	Armament Wt Fraction	2.3%	2.4%	0.0%
#L/DSP.FL	Armament Cap Size Ratio	.903	.938	3.9%
W.7/#L	Armament Spec Wt	26.0	26.0	0.0%
W.4/DSP.FL	C&S Weight Fraction	11.7%	12.2%	-.2%
#S/DSP.FL	C&S Capacity Size Ratio	1.264	1.314	3.9%
W.4/#S	C&S Specific Wt	92.8	92.6	-.2%
RELATED COMBAT SYSTEM RATIOS:				
W.csf/V1	Combat System Density	15.43	15.40	-.2%
W.4/V1.1	Command & Surv Density	23.44	23.38	-.3%
W.7/V1.2	Armament Density	14.03	15.34	9.3%
E.cs/W.csf	Combat Sys KW/Wt Ratio	NA	NA	NA
C.cs/W.csf	Combat Sys Cost/Wt Ratio	$447.16	$448.13	.2%

V4.2/SHP	Trans/Prop Spec Vol	NA	NA	NA
E.2/W.2	Prop KW/Weight Ratio	0.00	0.00	0.0%
C.2/W.2	Prop Cost/Weight Ratio	$94.76	$93.40	-1.4%

SCREEN 3-5: ELECTRICAL PLANT BREAKDOWN

WEIGHT:				
W.31/W.3	Power Generation Wt	38.1%	37.7%	0.0%
W.32/W.3	Power Distribution Wt	36.8%	37.6%	3.4%
W.33/W.3	Lighting Wt	8.4%	8.2%	-1.4%
W.34+39/W.3	Support Systems Wt	16.7%	16.5%	0.0%
VOLUME:				
V4.15/V.e	Machinery Box Elec Vol	NA	NA	NA
V4.33/V.e	Aux Space Elec Vol	NA	NA	NA

SCREEN 3-6: ELECTRICAL INDICES

ELECTRICAL DRIVERS:				
W.3/DSP.FL	Electrical Wt Fraction	4.5%	4.7%	1.1%
W.3/E.i	Electrical Spec Wt	92.7	93.8	1.1%
E.i/DSP.FL	Elec Capac Ship Size Ra	1.084	1.126	3.9%
RELATED ELECTRICAL RATIOS:				
W.3/V.e	Electrical Density	NA	NA	NA
V.e/VOL	Electrical Vol Fraction	NA	NA	NA
W.31/E.i	Power Gen Specific Wt	35.4	35.4	0.0%
V.e/E.i	Electrical Spec Vol	NA	NA	NA
E.3/W.3	Elec KW/Weight Ratio	NA	NA	NA
C.3/W.3	Elec Cost/Weight Ratio	$79.76	$67.86	-14.9%

SCREEN 3-7: AUXILIARY BREAKDOWN

WEIGHT:				
W.51/W.5	Climate Control Wt	23.4%	23.6%	-1.0%
W.52+53/W.5	Seawater/Freshwater Wt	20.2%	20.3%	-.9%
W.54+55+59/W.5	Fluid Systems Wt	24.8%	24.6%	-2.4%
W.56/W.5	Ship Control Wt	14.3%	14.1%	-3.0%
W.57+58/W.5	Replenish/Mech Hndlg Wt	17.2%	17.3%	-1.2%
VOLUME:				
V3.5/V.ax	Deck Systems Volume	71.8%	73.0%	-1.6%
V4.3-4.33/V.ax	Auxiliary Mach Volume	28.2%	27.0%	-7.4%

SCREEN 3-8: AUXILIARY INDICES

AUXILIARY DRIVERS:				
W.5/DSP.FL	Auxiliary Wt Fraction	11.5%	11.7%	-1.7%
W.5/VOL	Auxiliary Spec Wt	2.160	2.150	-.5%
VOL/DSP.FL	Ship Specific Vol	118.9	122.0	2.7%
RELATED AUXILIARY RATIOS:				
W.5/V.ax	Auxiliary Density	128.9	131.0	1.6%
V.ax/VOL	Auxiliary Volume Frac	1.7%	1.6%	-3.2%
E.5/W.5	Auxiliary KW/Wt Ratio	NA	NA	NA
C.5/W.5	Auxiliary Cost/Wt Ratio	$320.57	$315.18	-1.7%

W.16+17+19/W.1	Other Structural	4.2%	4.2%	-1.1%
OUTFIT AND FURNISHINGS:				
W.64+65+66+ 67/W.6	Crew Related	44.0%	44.3%	-.1%
W.61+62+63+ 69/W.6	Non-crew Related	56.0%	55.7%	-1.3%

SCREEN 3-2: CONTAINMENT INDICES

CONTAINMENT DRIVERS:				
W.1/DSP.FL	Structural Wt Fraction	23.5%	24.2%	-.8%
W.6/DSP.FL	Outfit & Furn. Wt. Frac	7.1%	7.3%	-.8%
W.1/VOL	Hull Struc Specific Wt	4.43	4.44	.4%
W.6/VOL	Outfit & Furn. Spec Wt	1.34	1.35	.4%
VOL/DSP.FL	Ship Specific Volume	118.9	122.0	2.7%
RELATED CONTAINMENT RATIOS:				
W.cf/V.c	Containment Density	17.4	17.3	-.3%
W.11+12+13+ 14/V.Hull	Basic Hull Struc Density	3.5	3.5	.8%
W.15/V.dh	Deckhouse Struc Density	3.3	3.3	-.1%
W.18/W.2+3+ 4+5+7	Foundations Wt Fraction	10.7%	10.9%	2.3%
C.c/W.cf	Containment Cost/Wt rat.	$84.04	$83.89	-.2%

SCREEN 3-3: MAIN PROPULSION BREAKDOWN

WEIGHT:				
W.23/W.2	Propulsion Units Wt	47.4%	52.1%	18.7%
W.24/W.2	Transmission/Prop Wt	29.1%	26.2%	-2.9%
W.25+26+29/W.2	Propulsion Support Wt	23.4%	21.8%	.4%
W.21+22/W.2	Other Propulsion Wt	0.0%	0.0%	NA
VOLUME:				
V4.1-4.15/V.pt	Propulsion Sys Volume	NA	NA	NA
V4.2/V.pt	Transmission/Prop Vol	NA	NA	NA

SCREEN 3-4: MAIN PROPULSION INDICES

MAIN PROPULSION DRIVERS:				
W.2/DSP.FL	Main Propulsion Wt Frac	7.8%	8.7%	8.2%
W.2/SHP	Main Propulsion Spec Wt	18.330	19.827	8.2%
SHP/DSP.FL	Main Prop Ship Size Rat	9.481	9.853	3.9%
R.Te/DSP.FL	Drag/Disp Ratio (endur)	18.309	19.421	6.1%
R.Ts/DSP.FL	Drag/Disp Ratio (sust)	59.985	62.978	5.0%
PC	Propulsion Coefficient	.718	.716	-.3%
RELATED MAIN PROPULSION INDICES:				
W.2/V.pt	Main Propulsion Density	NA	NA	NA
V.pt/VOL	Main Prop Volume Frac	NA	NA	NA
W.23/SHP	Prop Units Specific Wt	8.695	10.325	18.7%
W.24/SHP	Trans/Prop Specific Wt	5.342	5.188	-2.9%
W.25+26+29/SHP	Support/Fluids Spec Wt	4.297	4.314	.4%
V.pt/SHP	Prop & Trans Spec Vol	NA	NA	NA
V4.1-4.15/SHP	Prop Systems Spec Vol	NA	NA	NA

SCREEN 2-9: MANNING ALLOCATION

M.off/M.a	Officer Ratio	8.6%	8.0%	-7.7%
M.cpo/M.a	CPO Ratio	6.3%	6.3%	0.0%
M.enl/M.a	Crew Ratio	75.7%	74.8%	-1.3%
M.m/M.a	Manning Margin	9.3%	11.0%	17.9%

SCREEN 2-10: FUNCTIONAL MANNING ALLOCATION

M.cs/M.a	Combat Systems Manning	20.6%	19.9%	-3.2%
M.ops/M.a	Operations Manning	21.6%	21.3%	-1.5%
M.eng/M.a	Engineering Manning	16.6%	15.9%	-4.0%
M.na/M.a	Nav/Admin Manning	6.3%	6.3%	0.0%
M.sup/M.a	Supply Manning	11.6%	11.6%	0.0%
M.av/M.a	Aviation Manning	14.0%	14.0%	0.0%

SCREEN 2-11: BASIC CONSTRUCTION COST ALLOCATION

Note: Lead Ship Costs

C1/C.bc	Hull Structure	2.4%	2.4%	-.7%
C2/C.bc	Propulsion Plant	8.2%	8.6%	6.6%
C3/C.bc	Electric Plant	3.3%	3.3%	1.0%
C4/C.bc	Command and Surveillance	5.4%	5.3%	-.1%
C5/C.bc	Auxiliary	6.5%	6.3%	-1.3%
C6/C.bc	Outfit and Furnishings	3.1%	3.0%	-.6%
C7/C.bc	Armament	.3%	.3%	0.0%
C.m/C.bc	D+C Margin	3.6%	3.6%	2.1%
C.de/C.bc	Design/Engr (Gp 8)	51.5%	51.5%	1.7%
C.con/C.bc	Constr. Svcs/Assy (Gp9)	8.3%	8.2%	1.3%
C.pr/C.bc	Profit	7.4%	7.4%	1.6%
C.HM&E/C.BC	HM&E GFE	3.8%	3.8%	1.6%

SCREEN 2-12: FUNCTIONAL COST ALLOCATION

Note: Lead Ship Costs

C.cs/C.t	Combat Systems	47.1%	46.6%	.1%
C.ma/C.t	Machinery	38.9%	39.6%	2.8%
C.c/C.t	Containment	12.0%	11.8%	-.6%

SCREEN 2-13: COST FRACTIONS

C.csgfe/C.ls	Combat Sys GFE/Lead Ship	31.7%	31.4%	0.0%
C.csgfe/C.fs	Combat Sys GFE/Follow	52.8%	52.3%	0.0%
C.bcls/C.ls	Basic Constr/Lead Ship	51.1%	51.4%	1.6%
C.bcfs/C.fs	Basic Constr/Follow	40.7%	41.0%	1.5%
C.fs/DSP.fl	Follow Ship Cost/Weight	105.4	110.4	4.8%
C.fs/VOL	Follow Ship Cost/Volume	.887	.905	2.0%

SCREEN 3-1: CONTAINMENT WT BREAKDOWN

STRUCTURE WEIGHT:

W.11/W.1	Shell and Supports	29.5%	29.0%	-2.5%
W.12+13+14/W.1	Hull Struc Blkhds/Decks	37.0%	37.7%	1.0%
W.15/W.1	Deckhouse	12.0%	12.1%	-.4%
W.18/W.1	Foundations	17.3%	17.8%	2.3%

W3 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	KW INS. (KW)	KW/DSP (KW/ton)
FF-1006	1923	750	.39
FF-1033	1698	1000	.59
FF-1037	2537	2000	.79
FF-1040	3469	2000	.58
FF-1052	4014	3000	.75
FFG-7	3782	3000	.79
DD-692	3193	1000	.31
DD-931	3925	2500	.64
DD-963	7696	6000	.78
DDG-2	4505	2000	.44
DDG-37	5563	4000	.72
DDG-993	9029	6000	.66
DDG-51	8369	7500	.90
CG-26	7839	6900	.88
CG-47	9614	7500	.78

W4 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	# SENS	#/DSP (sr/kton)
FF-1006	1923	4	2.08
FF-1033	1698	4	2.36
FF-1037	2537	4	1.58
FF-1040	3469	5	1.44
FF-1052	4014	6	1.49
FFG-7	3782	6	1.59
DD-692	3193	4	1.25
DD-931	3925	4	1.02
DD-963	7696	5	.65
DDG-2	4505	6	1.33
DDG-37	5563	5	.90
DDG-993	9029	6	.66
DDG-51	8369	6	.72
CG-26	7839	6	.77
CG-47	9614	6	.62

where sr = sensor
kton = 1000 tons

W5 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	VOL (ft^3)	DSP/VOL (lbs/ft^3)
FF-1006	1923	199486	21.6
FF-1033	1698	242397	15.7
FF-1037	2537	290396	19.6
FF-1040	3469	407617	19.1
FF-1052	4014	503403	17.9
FFG-7	3782	531178	15.9
DD-692	3193	289030	24.7
DD-931	3925	414393	21.2
DD-963	7696	1034908	16.7
DDG-2	4505	484897	20.8
DDG-37	5563	639470	19.5
DDG-993	9029	1065367	19.0
DDG-51	8369	964013	19.4
CG-26	7839	857400	20.5
CG-47	9614	1102513	19.5

W6 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	VOL (ft^3)	DSP/VOL (lbs/ft^3)
FF-1006	1923	199486	21.6
FF-1033	1698	242397	15.7
FF-1037	2537	290396	19.6
FF-1040	3469	407617	19.1
FF-1052	4014	503403	17.9
FFG-7	3782	531178	15.9
DD-692	3193	289030	24.7
DD-931	3925	414393	21.2
DD-963	7696	1034908	16.7
DDG-2	4505	484897	20.8
DDG-37	5563	639470	19.5
DDG-993	9029	1065367	19.0
DDG-51	8369	964013	19.4
CG-26	7839	857400	20.5
CG-47	9614	1102513	19.5

W7 "TRIPLE PLOT" TREND DATA

SHIP	DSP.FL (tons)	# LCHR.	#/DSP (lr/Kton)	
FF-1006	1923	5	2.60	.033
FF-1033	1698	3	1.77	.024
FF-1037	2537	4	1.58	.028
FF-1040	3469	4	1.15	.028
FF-1052	4014	4	1.00	.037
FFG-7	3782	4	1.06	.026
DD-692	3193	8	2.51	.078
DD-931	3925	7	1.78	.070
DD-963	7696	6	.78	.020
DDG-2	4505	5	1.11	.057
DDG-37	5563	6	1.08	.051
DDG-993	9029	6	.66	.034
DDG-51	8369	6	.72	.039
CG-26	7839	5	.64	.041
CG-47	9614	7	.73	.038

where lr = launcher
kton = 1000 tons

END

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